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VOLTAGE REGULATION OF ALTERNATORS

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ENGINEERING EXPERIMENT STATION
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THE UNIVERSITY OF KANSAS
ENGINEERING EXPERIMENT STATION

Bulletin No. 1. November, 1909.

A BALLISTIC ELECTRODYNAMOMETER METHOD OF MEASURING HYSTERESIS LOSS IN IRON.

By MARTIN E. RICE and BURTON McCOLLUM.

In all electrical machinery containing large quantities of iron in which the magnetic flux is continually varied considerable power is expended due to magnetic hysteresis. This not only gives rise to a continual loss of energy, but this dissipated energy heats the apparatus. The latter effect is generally much more serious than the former, for the power output of an electrical machine is largely determined by the allowable heating; so it is evident that an excessive hysteresis loss very materially lowers the practical output and rating of a machine. It becomes, then, of great importance to the designer and to the manufacturer to be able to predetermine these hysteresis losses accurately. This requires that a sample of every lot of iron be tested before that iron is accepted and used, in order that only such iron shall be used as will make the hysteresis losses satisfactorily small. It is the purpose of this paper to present a new and accurate method for making such tests of iron.

A fairly complete test of the magnetic qualities of a sample of iron should include three things: The "B–H" curve, the hysteresis loop, and the hysteresis loss per cycle for any specified value of the maximum magnetic flux density. For nearly all commercial purposes it is sufficient to know the hysteresis loss per cycle for any specified value of the maximum magnetic flux density. The method here presented is an especially direct and rapid one for this purpose. The procedure is as follows:

The sample of iron to be tested should be laminated, the thinner the better. Laminations of ordinary commercial thickness, fifteen to forty mils., are satisfactory. The laminæ should be separated by sheets of paper. This insures that eddy current

losses will not be unduly increased by conduction from one sheet of iron to the next. The laminæ may be cut into the form of closed rings and wound by hand, the magnetic circuit then being a closed one; or they may be cut into the form of half rings and inserted into ready wound magnetizing and test coils, the magnetic circuit in this case having short air gaps. The latter arrangement, while perhaps not satisfactory for obtaining the true B–H curve, is practically as good for obtaining values of the maximum magnetic flux density and corresponding values of the hysteresis loss per cycle. It is also exceedingly convenient in that, when the apparatus has once been set up, many different samples of iron can be tested in a short time.

The chief instrument needed is a rather sensitive electrodynamometer that can be used ballistically. The fixed or field coils of the dynamometer should be capable of carrying the current used in magnetizing the iron under test; and the movable coil of the dynamometer should have a rather long period of oscillation, say thirty-five to forty seconds. The other instruments required include a standard mutual inductance, or a standard condenser and a standard cell; two reliable ammeters, resistance boxes, reversing switches, load rheostats and choke coils.

TO DETERMINE THE VALUE OF THE MAXIMUM MAGNETIC FLUX DENSITY, B.

This may be determined, if desired, by using a ballistic galvanometer in the ordinary way. If no good ballistic galvanometer is available, or if it is desired to make the complete test with a single ballistic instrument, as often might be the case in practical work, the value of B, and even the complete B–H curve, can be obtained by using the ballistic dynamometer as follows:

Maintain a steady current in the field coils of the dynamometer. The instrument can then be calibrated and used precisely as a D'Arsonval ballistic galvanometer. The necessary value of the magnetizing current, I, to produce a desired value of maximum magnetic flux density, B, in the iron under test can then be determined. Using a mutual inductance for calibrating purposes, the arrangement of circuits for obtaining values of magnetic flux density is shown in figure 1.

In the diagram, Fc represents the field or fixed coils of the electrodynamometer and Mc represents the movable coil of the instrument. M_1 represents the mutual inductance used in calibrating, n_2' being the secondary coil. The movable coil Mc of the

dynamometer can be connected at will to either the test coil on the iron C_2 or the secondary coil of the mutual inductance n_2' by the double-throw switch, as indicated by the dotted lines. The iron ring is marked Fe, and the rest of the diagram is self-explanatory.

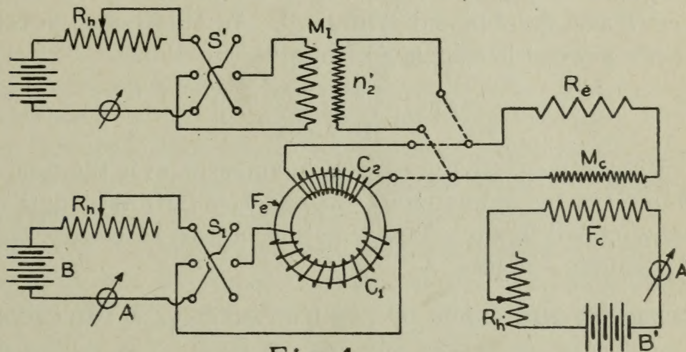


Fig. 1.

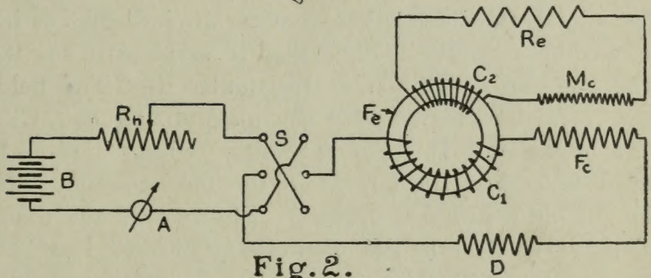


Fig. 2.

With the movable coil of the dynamometer connected to the test coil on the iron, reverse the magnetizing current, I, and note the dynamometer throw, d, a measured current, I″, being maintained in the field coils of the dynamometer; next, with the movable coil of the dynamometer connected to the secondary coil of the mutual inductance, reverse the current in the primary coil of the mutual inductance and note the dynamometer throw, d′, a measured current, I′, being maintained in the field coils of the dynamometer. The value of B in lines per cm^2 can then be calculated from the equation,

$$B = \frac{\varphi\, n'_2\, R_2\, d\, I'}{A\, n_2\, R'_2\, d'\, I''}, \qquad (1)$$

where R_2 and R'_2 are the total resistances in the circuit of the movable dynamometer coil, respectively; n_2 and n'_2 are the number of turns in the test coil and in the secondary coil, respectively; A

is the cross-sectional area of the iron under test; and φ is the total effective flux linking with the secondary coil of the mutual inductance and which is obtained by multiplying the current in the primary coil of the mutual inductance by the coefficient of mutual induction. If a suitable mutual inductance is available, I' can be made equal to I'', thus simplifying the equation. The complete B–H curve can be obtained if desired. In this case, the value of H in lines per cm^2 is calculated from the equation,

$$H = \frac{4\,\pi\,n_1\,I}{10\,L}, \tag{2}$$

where I is the magnetizing current in amperes, n_1 is the total number of turns in the nagnetizing coil, and L is the total length of the magnetizing coil in cm. This equation is true, of course, only for closed magnetic circuits.

TO DETERMINE THE VALUE OF THE HYSTERESIS LOSS PER CYCLE, W_h.

The arrangement of circuits is shown in figure 2. In this diagram, the coils of the electrodynamometer are indicated as in figure 1. The movable coil, Mc, is connected in series with the test coil, C_2, on the iron and an adjustable resistance, Re. The field coils, Fc, are connected in series with the magnetizing coil, C_1, on the iron and a choke coil, D. The reversing switch, S, should be so constructed as to close the circuit in the new position before the circuit in the old position is opened. The rest of the diagram is self-explanatory. Reverse the magnetizing current, I, and note the dynamometer throw, θ. Use the value of I corresponding to the value of B maximum desired, as determined by the arrangement in the preceding paragraph. The total loss, W, in joules per cycle in the iron under test can then be calculated from the equation,

$$W = 2\,\theta\,n_1\,\frac{2\,\Phi\,I'\,n'_2\,R_2}{10^8 d'\,n_2\,R'_2}, \tag{3}$$

where the letters have the meanings already given above. This value of energy loss per cycle includes a small and usally negligible eddy current loss. If it is desired, the eddy current loss can be calculated approximately and its value deducted from the above value of the total iron loss, thus giving the true hysteresis loss per cycle, W_h. To do this, observe the pointer of the ammeter in the magnetizing circuit of the iron under test while the current is being reversed and note the time required for the pointer to fall and rise again to its former position. This is, roughly, the time of a half

period of the hysteresis cycle. The eddy current loss, W_c, in joules per cycle in the iron under test is computed from the equation,

$$W = 1.645\, t^2 f B^2 V 10^{-11}, \qquad (4)$$

where t is the thickness of a lamina in cm., f is the reciprocal of the period of the cycle, B is the maximum magnetic flux density in lines per cm^2, and V is the volume of the iron in cm^3. By inserting a choke coil in the magnetizing circuit of the iron under test, the period of the hysteresis cycle can be made so long, one to three seconds, that the eddy current loss will be less than one per cent of the total iron loss. In such cases a very rough estimate of the time of the period of the hysteresis cycle will enable the eddy current loss to be computed with ample accuracy.

Thus, when the apparatus has been set up and calibrated, one reading suffices to determine the value of the maximum magnetic flux density, B, and another reading to determine the hysteresis loss per cycle, W_h. Each reading has only to be multiplied by a single numerical factor to give the final result desired. Hence it is possible to test a large number of samples of iron and to compute the final results in a comparatively short time. A complete numerical illustration follows, the data being taken from one of the tests made by the writers on a sample of rather heavy sheet iron. The iron was in sheets of twenty-five mils. thickness, and was cut into the form of closed rings. Thirty of these rings were assembled and wound with a magnetizing coil and a test coil. The mean dimensions were: Length of magnetic circuit, L = 60.66 cm.; cross section of iron, A = 4.195 cm^2; volume of iron, V = 254.5 cm^3; the thickness of a lamina, t = .0635 cm. With steady currents maintained in the field coils of the dynamometer, throws were observed with the movable coil connected to the test coil of the iron and to the secondary coil of the mutual inductance, respectively. A value of current in the primary of the mutual inductance was used which gave a total magnetic flux in the secondary coil of $\varphi = 58{,}735$ lines. Substitution in equations (1) and (2) gives

$$B = \frac{58{,}735. \times 10. \times 1242.4 \times d \times 1.486}{4.195 \times 20. \times 1242. \times 10.34 \times 1.446} = 677.0 \times d.$$

$$H = \frac{4 \times 3.1416 \times 272 \times I}{10 \times 60.66} = 5.636 \times I$$

The values of d and I used were d = 17.34 cm and I = 1.446 amperes, giving B = 11740, and H = 8.15, each in lines per cm^2. Data for a complete B–H curve can be obtained by taking a number

of corresponding readings of d and I. Substitution in equations (3) and (4) gives

$$W = 2 \times \theta \times 272 \times \frac{2 \times 58.735. \times 1.486 \times 10. \times 1245.6}{10^8 \times 10.34 \times 60. \times 1242.} = .01533 \times \theta$$

$$W_e = 1.645 \times (.0635)^2 \times .5 \times B^2 \times 254.5 \times 10^{-11} = .833 \times 10^{-11} \times B^2.$$

The value of B was the same as above and the value of θ was 11.48 cm., giving the total iron loss per cycle, $W = .1760$, and the eddy current loss per cycle, $W_e = .001146$, each expressed in joules.

The difference, $W - W_e$, gives the true hysteresis loss, $W_h = .1748$ joules per cycle. Dividing this result by the volume, V, of the iron under test gives the hysteresis loss in joules per cycle per cubic centimeter, namely, .000687 joules. The value of W_e is usually so small, as in the above illustration, that for nearly all commercial work it can be entirely neglected. The hysteresis loss, W_h, is then given immediately by the expression for the total iron loss, W, thereby shortening the calculations materially.

The writers have shown* by mathematical proof that the ballistic dynamometer measures both the iron loss and the loss in the test-coil circuit. By making the period of reversal of the magnetizing current long, say one to one and a half seconds, the eddy current loss in the iron can be kept below one per cent of the total iron loss. This can be accomplished by adding one or more choke coils in series with the magnetizing circuit, sufficient to make the period of reversal of the desired length. The I^2R loss in the test-coil circuit can easily be made entirely negligible by using a moderately high value of R_2. The first of the above conditions requires that the period of swing of the movable coil of the dynamometer shall be relatively long, say thirty-five to forty seconds, in order that the discharge through the movable coil of the dynamometer shall have taken place before the coil has moved appreciably. The writers have shown experimentally that when the period of swing of the dynamometer coil is thirty or forty seconds, no appreciable error is introduced by making the time of reversal of the magnetizing current as great as one and a half seconds.

Referring to equation (3) for calculating the total iron loss per cycle, W, it is seen that the quantities to be measured are θ, ϕ, I', d', R_2, R'_2. The value of R_2/R'_2 can easily be determined with an error of 0.2 per cent or less, if ordinary precautions are taken against wide variations in temperature. The value of I'/d' can

* Physical Review, vol. xxviii., No. 2, August, 1909.

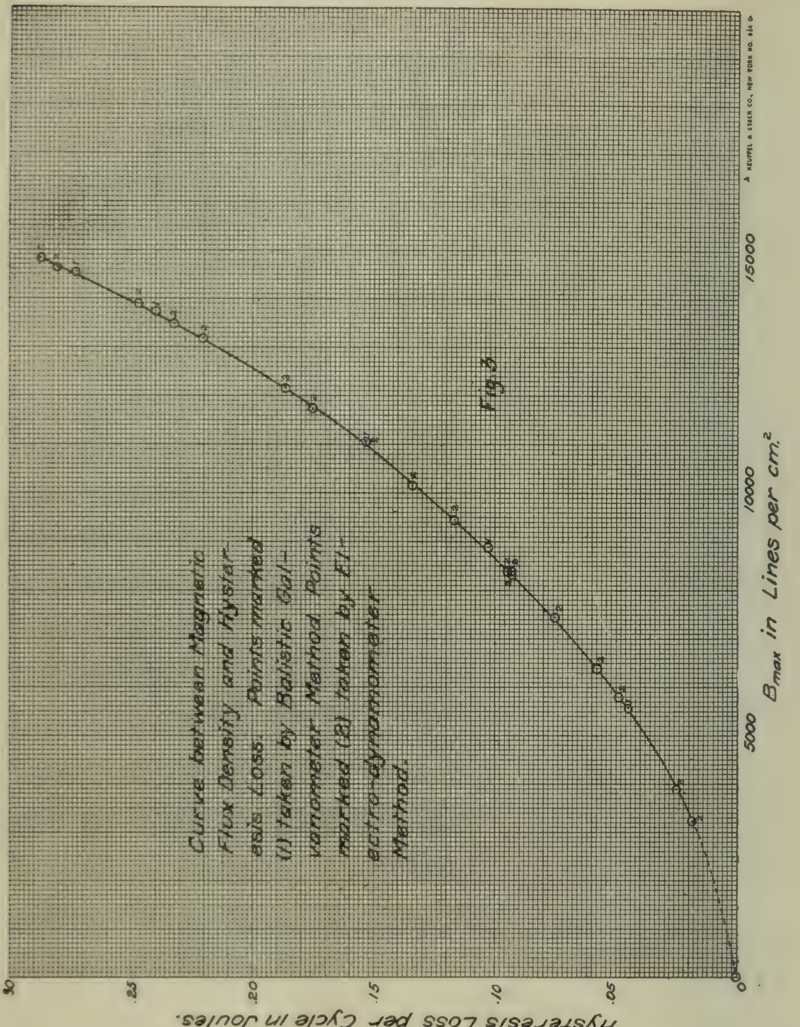
usually be determined with an error of 0.3 per cent or less. The value of ϕ can be relied upon as closely as the ammeter reading in the primary coil of the mutual inductance, which, if a good instrument is used, should be accurate to within 0.2 per cent. The value of θ can be read easily within 0.2 per cent with such slow moving instruments. If all these errors should combine to affect the value of W in the same way, the total error in W would be 0.7 per cent or less. Since the eddy current loss, W_c, is usually considerably less than 1 per cent of the total iron loss, W, even a very rough estimate of its value would enable the true hysteresis loss, W_h, to be determined with a maximum error of 1 per cent or less. This degree of accuracy is readily attainable with good instruments.

As a further comparison, the writers made a test of a sample of good transformer iron in sheets of fifteen mils. thickness, by both methods. In this case the electrodynamometer was calibrated by means of a condenser and standard cell. The results were: By the dynamometer method, hysteresis loss in sample ring = .05747 joules per cycle for B maximum = 7548 lines per square centimeter; by the ballistic galvanometer method, hysteresis loss = .05732 and B = 7552. This agreement is well within the limits of experimental error.

A similar examination of the equations employed in the ballistic galvanometer method shows about the same degree of accuracy attainable, theoretically. In practice, this accuracy may be realized if the new single step procedure suggested by A. Hoyt Taylor in the *Physical Review* (vol. XXIII, p. 95) is followed. If the old and ordinary, successive step by step, procedure is followed, far less accuracy can be hoped for, if, indeed, any accuracy at all is attainable. By either procedure, data for at least fifteen or twenty points must be taken, a curve plotted and its area in B−H units determined, so that the test of a sample of iron by the ballistic galvanometer method is a considerable task.

In figure 3 are given the comparative results of a series of tests made by the writers on a sample of sheet iron. One set of points was obtained by the ballistic dynamometer method and the other set of points by the ballistic galvanometer method, using the single step procedure. It is noted that both sets of points fall on the same curve within the limits of error discussed above.

In regard to the comparative time required to test a sample of iron by the dynamometer method and by the galvanometer method, it is only necessary to note that the single reading required by the



former method can be taken as quickly as any one of the many readings required by the latter method. Further, when using the dynamometer method it requires but a few moments to calculate the final results from the data obtained; while with the ballistic galvanometer method it is necessary to go through the tedious operation of plotting a curve, measuring its area with a planimeter, and then calculating the final results.

It is thus seen that by the ballistic dynamometer method of testing the hysteresis loss in iron, results of the same accuracy are obtained as by the very tedious ballistic galvanometer method in its best form. And these results are obtained with equal or greater rapidity than by the other admittedly far less accurate methods commonly employed.

Before concluding this paper, it may be helpful to others using the ballistic dynamometer method for the first time to mention some of the precautions that should be taken in any such work and to describe a suitable electrodynamometer. In all work of this character four readings should be taken for each point: two with fixed test-coil connections, the primary or magnetizing current being reversed once in each direction; two with reversed and fixed test-coil connections, the primary current being again reversed one in each direction as before. This procedure eliminates all effects of stray magnetic fields on the iron under test and on the movable coil of the dynamometer. It should be followed in both the ballistic dynamometer method and the ballistic galvanometer method, and for the same reasons. It is preferable to set the dynamometer in such a position that a current in its movable coil will not cause a deflection due to the magnetic field of the earth. All ballistic deflections, taken by either method, should be corrected for damping in the usual way. If a series of readings is to be taken requiring a very wide variation of current in the magnetizing circuit, it is best to vary this current partly by changes in the voltage supplied rather than to depend entirely upon changes in resistances, in order that the time constant of the magnetizing circuit be kept large for all values of current used. This keeps the period of the hysteresis cycle sufficiently long to insure a small value of eddy current loss.

If a suitable electrodynamometer is not at hand, one may be made as follows: Suspend the moving coil of a D'Arsonval galvanometer in the usual manner, using a rather long fine strip above. If its period of swing is not long enough, it may be increased by fixing two small weights at opposite ends of a light wooden strip attached horizontally to the movable coil. The moving coil and its suspensions should be inclosed to protect it from air currents and sudden changes in temperature. The field coils may consist of two large coils of heavy wire set close to the case containing the movable coil and large enough to give a field

throughout the region occupied by the movable coil. All masses of metal, such as brass tubes or cases, should be rigidly avoided in the construction of such an instrument, in order to avoid entirely any disturbing effects from eddy currents.

LABORATORY OF PHYSICS AND ELECTRICAL ENGINEERING,
APRIL, 1909.

VOLTAGE REGULATION OF ALTERNATORS.

By Burton McCollum.

When an alternator is running under load the full voltage generated by the machine is not available at the terminals or bus bars, because a portion of the voltage generated is used up in forcing the current through the resistance and reactance of the armature coils. In consequence of this, the voltage at the terminals of an alternator tends to fall off as the load is increased. Conversely, when an alternator is running under a given load and yielding a certain voltage at its terminals, if the load be decreased the terminal voltage will rise. The total rise of voltage at the terminals of an alternator when the load is changed from full load to zero, expressed as a percentage of the full load terminal voltage, is called the voltage regulation of the alternator.

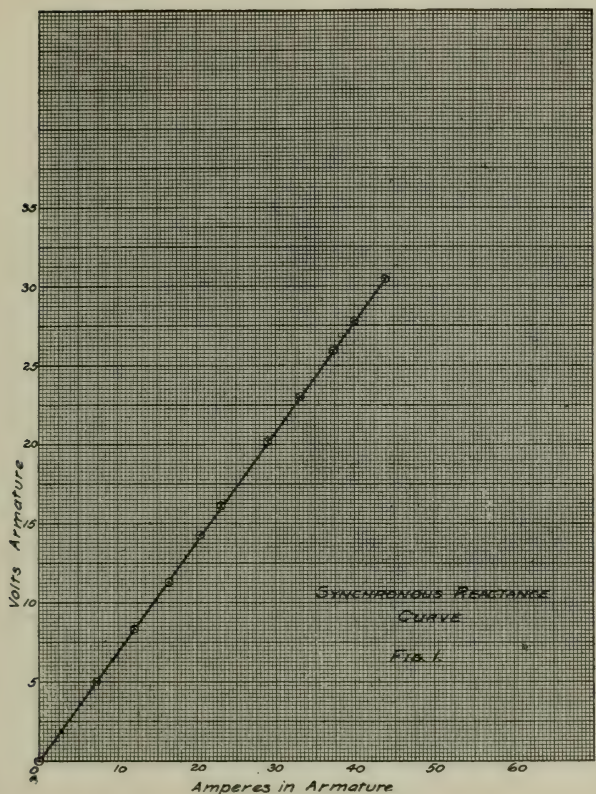
This tendency of an alternator to change its voltage with every change of load is of great importance in the practical operation of the machines, inasmuch as the successful operation of most kinds of electrical receiving apparatus, and more especially of incandescent lamps, requires a very constant voltage at the supply mains. A reduction of a very small per cent in voltage supplied to an incandescent lamp reduces in vastly greater degree the brightness and efficiency of the lamp, and an increase of the voltage above normal, while it increases the brightness of the lamp, is wasteful of energy and greatly reduces the life of the lamp. Moreover, since the load of an alternator is continually changing more or less the consequent pulsation of the voltage may often cause objectionable flickering of the lamp. It is seen, therefore, that the voltage regulation of an alternator, or its change of voltage from no load to full load, should be as small as possible. It is important, therefore, in buying an alternator, especially for lighting, to specify that the regulation shall be within certain limits, the allowable limits depending to some extent on the size of the machine, but more especially on the power factor of the load. It is common practice to require the manufacturer to guarantee that the regulation shall not be greater than a certain per cent at a specified power factor, and so it becomes important to have some accurate and convenient means to determine the regulation of the machine under any specified conditions before it leaves the factory, and in many cases the

purchaser desires to determine the regulation of the machine after it is installed but before accepting it from the manufacturer.

One method of determining the regulation of an alternator is simply to load the machine with a load of amount and power factor called for in the contract and measuring the per cent rise of voltage when the load is thrown off. This is the method generally used with very small machines, but when larger machines are to be tested this is impracticable. In the power house where the machine is installed it may often be difficult to fulfill accurately the conditions called for in the contract, while in the factory, where a suitable load is never available, the problem of providing the rheostat and inductances necessary to give the required load and power factor is too serious to be considered. It is, therefore, necessary to resort to some method of calculating the regulation from data that can be secured without loading the machine. This is a problem which has not heretofore been fully worked out, methods which are only approximate being depended upon to give the desired information. Two such methods have found wide application, the so-called "optimistic" and "pessimistic" methods,* they being so called because the former generally gives a regulation smaller or better than the true value, while the latter generally gives a larger or poorer regulation than the machine actually shows in operation. These methods can generally be depended upon to give the limits between which the true regulation lies, but inasmuch as these limits are generally rather widely separated it is usually difficult to form any very accurate estimate of the true regulation of the machine. However, by making a comparatively simple and easily executed modification of these methods the writer has been enabled to eliminate the principal source of error, and therefore to determine accurately the voltage regulation of the machine from readings easily taken without loading. Before describing how this is accomplished it will be necessary to describe briefly the methods referred to above and to point out the sources of error inherent in them.

In determining the voltage regulation by the "pessimistic" method, we plot what is called the synchronous reactance curve (fig. 1), which is obtained by applying a low field excitation and short-circuiting the armature through an ammeter. The ammeter is read and then the armature circuit opened, and the resulting

*Transactions American Institute of Electrical Engineers, vol. XXI. "The Experimental Basis for the Theory of the Regulation of Alternators," B. A. Behrend.



voltage across the armature terminals is read with a voltmeter. The curve is plotted between terminal volts as ordinates, and corresponding short-circuit currents as abscissas. The voltage in each case is assumed to be that necessary to force the corresponding current through the armature at synchronous speed; that is, it is the electromotive force consumed in the impedence of the armature at that particular value of current. And since the total armature impedence is practically equal to its reactance, this electromotive force may be regarded as the reactance drop in the armature, and is therefore at right angles to the current in the vector diagram. Drawing now the voltage diagram of the alternator with current vector as axis of reference (fig. 2), and terminal voltage, E, leading the current by an angle θ, where θ is the phase angle of the load circuit, we have superposed upon this voltage the Ir drop in phase with the current and the reactance drop Ix at right angles to the current. The vector sum of these com-

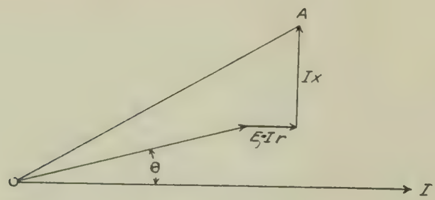


Fig. 2.

ponents, OA, gives the total generated voltage in the armature, and this is the value to which the terminal voltage would rise if the load were thrown off. It is easily seen from the diagram that the total components of OA are $E \cos \theta + Ir$ parallel to I, and $E \sin \theta + Ix$ at right angles to I. Therefore,

$$OA = \sqrt{(E \cos \theta + Ir)^2 + (E \sin \theta + Ix)^2} = E_t. \qquad (1)$$

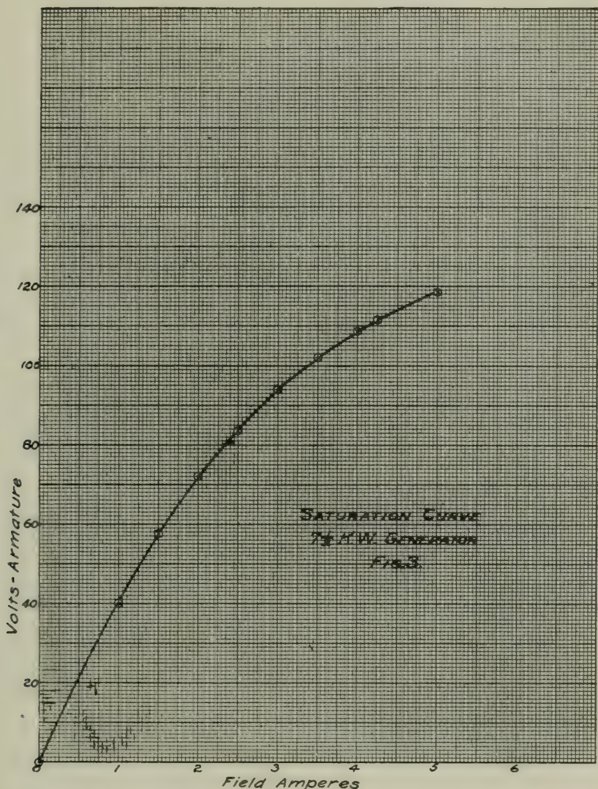
The regulation therefore =

$$\frac{E_t - E}{E} \qquad (2)$$

In applying the "optimistic" method an additional curve is necessary, viz., the saturation curve, which is the curve plotted between terminal volts as ordinates and field excitation as abscissas. This curve is shown in figure 3. Instead of calculating the value OA (fig. 2) directly, as in the "pessimistic" method, we take the two components, $E \cos \theta + Ir$ and $E \sin \theta + Ix$, and by reference to the saturation curve we find the field excitation, f_1, necessary to produce the component of electromotive force, $E \cos \theta + Ir$, and also the excitation, f_2, necessary to produce the component of electromotive force, $E \sin \theta + Ix$.

Since these electromotive force components are at right angles to each other it is assumed that if the components of field excitation, f_1 and f_2, are superposed at right angles to each other their resultant $\sqrt{f_1^2 + f_2^2}$ will be the excitation required to produce the resultant electromotive force, OA. Then from the saturation curve the terminal voltage corresponding to the excitation $\sqrt{f_1^2 + f_2^2}$ is read off, and this is taken as the value to which the terminal voltage would rise when the load is thrown off.

In applying these methods several important sources of error are ignored. In the first place, the reasoning is based on the assump-



tion that the saturation curve of the machine is a straight line. A second source of error lies in the fact that no account is taken of the fact that the synchronous reactance of the armature is a function of the position of the armature magnetomotive force with respect to the poles of the field, and is therefore dependent on the power factor of the load. At very low power factor the magnetomotive force of the armature is nearly opposite to the magnetomotive force of the field, and in this position the armature reactance is a maximum. At unity power factor, on the other hand, the magnetomotive force of the armature is at right angles to the field, and, since in most alternators this is the position of maximum reluctance, the reactance of the armature in this position is a minimum.

It follows, therefore, that in calculating the regulation of the armature at unity power factor the minimum value of reactance is the one to be taken, while calculating the regulation at zero power factor the maximum value is the one to be used, and in determin-

ing the regulation at intermediate power factors an intermediate value should be taken, or preferably, as will be shown later, a method used which is equivalent thereto. It is obvious that the synchronous reactance curve as ordinarily taken gives the reactance of the armature in one position only, viz., that in which the magnetomotive force of the armature is opposed to that of the field, since the current in the short-circuited coils lags nearly ninety degrees behind the electromotive force, and hence the value of reactance obtained is the maximum value. It is the correct value to use in calculating the voltage regulation of the machine at zero or very low power factor, but is in general far larger than the reactance of the armature for currents of higher power factors. And since alternators in practice are generally operated at power factors between 0.80 and unity, it follows that, if the value of the synchronous reactance as taken from the short-circuited readings in the ordinary way be taken as the basis for calculating the regulation, too large a value will be attained. Hence the term "pessimistic" as applied to this method.

With a view to eliminating the error inherent in the method described the writer has made use of another method for determining the reactance of the armature by which one may readily determine the synchronous reactance of the armature in any desired position of the armature with respect to the poles, and, therefore, the value to be used in calculating the regulation for any power factor. In making use of this method the alternator is driven at normal speed without field excitation, by means of a small auxiliary motor. Low polyphase electromotive forces obtained from an independent source of supply, either directly or through a bank of transformers, are applied to the armature, and a current which need not be more than a fraction of full-load current is sent through the armature. If the speed of the alternator be adjusted until it is running synchronously with the supply electromotive force, the magnetomotive force of the armature will bear a fixed relation to the field poles, and if the ammeter is placed in series with the line and voltmeter across the armature terminals, the ratio of volts to amperes will give the reactance of the armature in that particular position. Now if the speed of the alternator be momentarily accelerated until it has gained a few degrees in the supply source, the armature magnetomotive force will bear a different relation to the field and the ratio of volts to amperes will, in general, show a different value of reactance. Thus, if the alternator be made to run

very slightly faster or slower than the supply and the supplied voltage held constant, the ammeter will pulsate slowly between maximum and minimum values, these values varying in general between wide limits.

If we take the reading of the voltmeter and ammeter when the ammeter reading is a minimum, the ratio of these readings will be the reactance of the armature when at its maximum, and hence the value to be used in calculating the regulation at zero power factor. If we take the readings when the ammeter reading is a maximum, the ratio of volts to amperes gives the minimum value of reactance and the value to be used in calculating the regulation at unity power factor. By taking readings of intermediate points we could similarly calculate the synchronous reactance of the armature at intermediate positions and use these values in calculating the regulation for power factors between zero and unity. Thus the reactance of the armature when shifted θ electrical degrees from the position of its minimum value would be the value to use in calculating the regulation of the machine for a power factor equal to $\cos\theta$.

It is not practicable, however, nor is it at all necessary, to determine the reactance at points intermediate between the maximum values. To do so would require somewhat elaborate apparatus, such as a stroboscope, for example, for determining the exact position of the armature at the instant of taking a reading. The maximum and minimum values can, however, be quickly and accurately taken, and it can be readily shown that these values alone are sufficient to enable one to accurately calculate the voltage regulation of the machine for any power factor.

In determining the voltage regulation of an alternator by this method the procedure is an follows: Determine the maximum and minimum values of the synchronous reactance as described above. For the case of unity power factor the smallest value of reactance is taken and the calculation carried out exactly as in the "pessimistic" method described above. The difference in the result obtained is due simply to the fact that there the value of reactance at unity power factor is taken instead of the reactance at zero power factor. For the case of power factor less than unity we proceed as follows:

Let X_1 = mimimum value of reactance.

Let X_2 = maximum value of reactance.

Let $\cos\theta$ = power factor.

Let r = resistance per phase of alternator.

Let I = current for which regulation is to be calculated.

Let E = terminal voltage of alternator at full load.

The energy component of current is therefore equal to $I \cos \theta$. The wattless component of current $= I \sin \theta$. The voltage drop due to each of these components of current may be calculated as if the other did not exist, and these components superposed on the vector diagram in proper phase relation will give the total resultant drop of voltage due to the synchronous reactance. It is obvious that the energy component of current, $I \cos \theta$, must flow through the minimum value of reactance, and the electromotive force consumed by this component is therefore equal to $X_1 I \cos \theta$, and is ninety degrees ahead of the energy current and hence in quadrature with the terminal electromotive force, E (fig. 4); also, the wattless component of current, $I \sin \theta$, must flow through the armature in position of maximum reactance, and hence the electromotive force consumed by this component is $X_2 I \sin \theta$; and since this component of electromotive force is as before ninety degrees ahead of the wattless current to which it is due, it is therefore in phase with the terminal electromotive force. We have also to take into account the electromotive force necessary to force the energy current through the resistance, viz., $rI \cos \theta$ in phase with $I \cos \theta$, and therefore with E, and the electromotive force required to force the quadrature current through the resistances, $rI \sin \theta$, ninety degrees behind E.

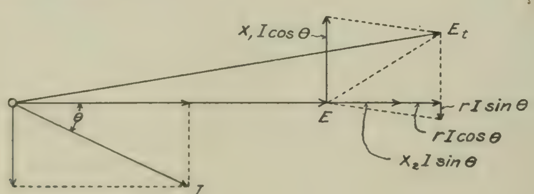


Fig. 4

Therefore the generated voltage of the machine E_t, the value to which the terminal voltage will rise when the load is thrown off, is given by the equation:

$$E_t = \sqrt{(E + X_2 I \sin\theta + rI \cos\theta)^2 + (X_1 I \cos\theta - rI \sin\theta)^2}. \qquad (3)$$

And the voltage regulation is, $N = \dfrac{E_t - E}{E}$.

For unity power factor, $\sin\theta=0$ and $\cos\theta=1$, equation (3) reduces to $E_t=\sqrt{(E+rI)^2+X_1I^2}$. (4)

For very low factors, $\sin\theta=1$ and $\cos\theta=0$, equation (3) becomes $E_t=\sqrt{(E+X_2I)^2+\bar{r}I^2}$. (5)

In the foregoing we have neglected, for the sake of simplicity, the effect of magnetic saturation in the field structure. In many cases, where the saturation curve of the alternator is sensibly a straight line, it is not necessary to make any correction for this effect. But in some cases, where the iron is worked well up on the saturation curve, a correction is necessary if accurate results are to be obtained. The reluctance of the cross-magnetization path of the armature, that is, in a direction at right angles to the axis of the pole, which is, of course, the reluctance of the magnetic path which links with the energy component of current, is but slightly affected by the saturation of the iron, and therefore the value, X_1, in the foregoing discussion requires no correction for ordinary conditions of saturation. The reluctance of the magnetic circuit parallel to the axis of the poles is, on the contrary, very considerably increased when the iron becomes saturated, and, since the the value of X_2 above is taken without field excitation, the value thus obtained will in general be higher than the actual value under load conditions with full field excitation. The correction for this is easily made, as follows: Plot the saturation curve as shown in figure 5. Take the value of $X_2I\sin\theta$, obtained as above, and

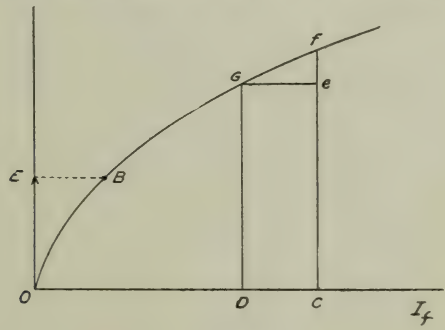


Fig. 5.

lay off this value on the electromotive force axis, giving OE. The line EB parallel to OI_f gives the magnetomotive force of the wattless component of current reduced to field amperes. Now take OC as the full-load excitation of the machine and lay off CD, equal to EB,

and draw Cef, DG parallel to Cef, and Ge parallel to DC. Then Ge = EB and the line ef represents the drop of voltage due to the wattless component of current at the chosen field excitation where OE is the drop due to the same current at low field excitation. Therefore the reactance X_2 is reduced in the ratio $\frac{ef}{OE}$ by the saturation of the iron, and hence the true reactance to be used in equation (3), instead of X_2, is $X_3 = X_2 \frac{ef}{OE}$.

The following numerical calculations will serve to make clearer the operations necessary in carrying out this method, and will permit of a comparison between the results obtained by the three methods of calculation and those obtained by experimental tests on a small alternator. The machine used was a 7½-kw., 110-volt, 60-cycle, three-phase △ connected alternator with revolving armature. The saturation curve is shown in figure 2 and the synchronous reactance curve in figure 1. The resistance per phase as determined by direct current measurement was 0.075 ohms. The regulation is determined for a current of forty amperes and a full-load voltage of 110 volts.

Case I, unity power factor: Applying the "pessimistic" method, we find from the synchronous reactance curve that the reactance volts corresponding to forty amperes are 27.7, equals IX in the vector diagram (fig. 6). The resistance volts at 23.1 amperes per phase $= \left(\frac{40}{\sqrt{3}}\right)$ are 1.73, = Ir in the diagram. We have therefore as the total generated voltage, and therefore the voltage to which the machine will rise when the load is removed, the vector E_t. This is readily seen to be $E_t = \sqrt{(110 + 1.73)^2 + 27.7^2} = 115.1$. Therefore, the voltage regulation as determined by the "pessimistic" method is

$$N = \frac{E_t - E}{E} = \frac{115.1 - 110}{110} = 4.6 \text{ per cent.}$$

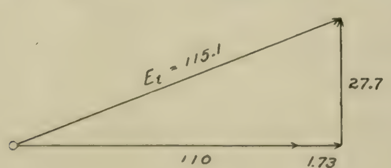


Fig. 6.

Applying the "optimistic" method, we find from the saturation curve (fig. 3) that the field excitation corresponding to the voltage of $111.73 = 4.26$ amperes and that corresponding to the voltage $27.7 = 0.7$ amperes. Therefore the field excitation corresponding to the total generated voltage $= \sqrt{4.26^2 + .7} = 4.31$ amperes. From the saturation curve the voltage corresponding to this excitation is 112.2 volts. Therefore the voltage regulation as determined by the "optimistic" method is

$$\frac{N = 112.2 - 110}{110} = 2 \text{ per cent.}$$

Applying now the method proposed above we find the synchronous reactance varies between a minimum of 0.42 ohms and a maximum of 0.6 ohms. Since the current in this case is all energy current, that is, in phase with the electromotive force, only the smaller of the above values need be used. The reactance voltage therefore equals $.42 \times 40 = 16.8$, and the total generated voltage is

$$E_t = \sqrt{(110+1.73)^2 + 16.8^2} = 113 \text{ volts.}$$

Therefore the voltage regulation as determined by this method is,

$$N = \frac{113 - 110}{110} = 2.73 \text{ per cent.}$$

As a criterion of the comparative accuracy of the above methods the voltage regulation was determined experimentally by actually loading on noninductive resistance. The full-load voltage was 110 volts, the no-load voltage 113.1 volts. Therefore the true regulation was

$$N = \frac{113.1 - 110}{110} = 2.81 \text{ per cent.}$$

By comparing these results we find that the regulation as determined by the "pessimistic" method is 63 per cent too high. As determined by the "optimistic" method it is 28.9 per cent too low, while by the method herein proposed it is 2.9 per cent low. This last is a satisfactory agreement.

Case II, power factor $.82 = \cos\theta$, terminal voltage 110, current 40 amperes: Applying "pessimistic" method we have: e. m. f. in phase with current $= E \cos\theta + Ir = 110 \times .82 + 1.73 = 91.9$ volts; e. m. f. in quadrature with current $= E \sin\theta + Ix = 110 \times .57 + 27.7 = 90.4$. Therefore the total generated voltage is

$$E_0 = \sqrt{91.9^2 + 90.42^2} = 128.9 \text{ volts.}$$

Hence the regulation by the "pessimistic" method is

$$N_1 = \frac{128.9 - 110}{110} = 17.2 \text{ per cent.}$$

By the "optimistic" method we have—

Excitation required to produce 91.9 volts = 2.96 amperes.

Excitation required to produce 90.4 volts = 2.92 amperes.

Resultant excitation $= \sqrt{2.96^2 + 2.92^2} = 4.1$ amperes.

From saturation curve we find corresponding terminal voltage to be 109 volts. Therefore the regulation as determined by the "optimistic" method is

$$N_2 = \frac{109 - 110}{110} = -0.9 \text{ per cent.}$$

This is clearly an absurd result, as it is impossible to have a negative regulation with lagging current. It is however, a result very frequently obtained by this method when the field is worked near saturation with power factory less than unity. Applying now the proposed method as set forth above we have—

Energy component of current $I_1 = 40 \times .82 = 32.8$ amperes.

Watless component of current $I_2 = 40 \times .57 = 22.8$ amperes.

As in case I, the minimum value of reactance $X_1 = .42$ ohms.

the maximum value of reactance $X_2 = .6$ ohms.

Hence the quantities to be substituted in equation (3) are

$$I_1 r = \frac{32.8}{\sqrt{3}} \times .075 = 1.42 \text{ volts.}$$

$$I_2 r = \frac{22.8}{\sqrt{3}} \times .075 = .98 \text{ volts.}$$

$$I_1 X_1 = 32.8 \times .42 = 13.7 \text{ volts.}$$

$$E = 110 \text{ volts.}$$

We also have $I_2 X_3 = I_2 X_2 \dfrac{ef}{OE}$ as explained above. From the saturation curve it is seen that $\dfrac{ef}{OE} = .25$. Hence $I_2 X_3 = 22.8 \times .6 \times .25 = 3.5$ volts. Substituting these values in equation (5) we have $E_t = \sqrt{(110 + 1.42 + 3.5)^2 + (13.7 - .98)^2} = 115.6$.

Therefore the regulation is

$$N_3 = \frac{115.6 - 110}{110} = 5.1 \text{ per cent.}$$

In determining the regulation experimentally for this case we had: Full-load volts, 110; no-load volts, 115.9. Hence the regulation is

$$N = \frac{115.9 - 110}{110} = 5.3 \text{ per cent.}$$

Collecting the results for case II for comparison we have values of regulation as determined by

Pessimistic method	=	16 per cent.
Optimistic method	=	−0.9 per cent.
Proposed method	=	5.1 per cent.
Experiment	=	5.3 per cent.

Here again we find the values obtained by the first two methods widely at variance with the experimental value, and a close agreement between the values obtained by experiment and by calculation by the foregoing method. In determining the synchronous reactance as above described it is not advisable to determine the reactance by sending full-load current through the machine. When the currents approach full-load values the machine tends to develop enough synchronous motor action to hold the field in a definite position with respect to the armature magnetomotive forces, and it thus becomes difficult to make the machine run at speeds slightly different from that of the supply source. However, since in most cases the synchronous reactance curve is sensibly a straight line, it is not necessary to use more than a fraction of the normal current, the ratios of impressed electromotive force to current being practically the same for all values of current up to that of full load. It is important to note that before determining the synchronous reactance in this way the residual magnetism should first be removed, as it tends to introduce an appreciable error in the result. If care be taken in this regard accurate results should be obtained.

LABORATORY OF PHYSICS AND ELECTRICAL ENGINEERING.
APRIL, 1909.

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ENGINEERING BULLETIN No. 3.

KANSAS FUELS: COAL, OIL, GAS.

HEATING VALUES AND PROXIMATE ANALYSIS OF COAL.

BY

P. F. WALKER AND WALTER BOHNSTENGEL.

DISCUSSION OF SULPHUR CONTENT OF BITUMINOUS COAL.

BY

WALTER BOHNSTENGEL.

LAWRENCE, KANSAS.

Published Semimonthly from January to June and Monthly from July to December, inclusive, by the University of Kansas.

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of the Engineering Departments.

The Station designs to issue bulletins, of which this is the third number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

PREFACE.

The work represented in this bulletin has been under way for several years in the Mechanical Engineering Department laboratory. Several men besides the authors have had to do with it, notably Prof. Charles I. Corp, now of the University of Wisconsin, who collected many samples and did much to inaugurate the investigation on coal, and Mr. Albert F. Smethers, for a year laboratory assistant in the department and now engaged in practical engineering work, who prepared many laboratory samples and started the proximate analyses. Mr. Bohnstengel did most of the analytical and calorimetry work on coal, while in the position of laboratory assistant, that work having been completed and much of the final preparation of the report made since he became a member of the staff of the engineer of tests on the A., T. & S. F. Railway, in which position he has continued his fuel work and checked out many important points. The work on oil and gas has, in most part, been done by Professor Walker, aided by Prof. F. W. Bushong, of the Department of Industrial Chemistry Research of the University, in oil analyses, and by Prof. H. C. Allen, of the Department of General Chemistry, in gas analyses. The notable work of Professors Cady and McFarland of the Chemistry Department in their investigation of the constituents of natural gas has been drawn upon in some measure.

In matters relating to extent and stratigraphy of the fuel fields, and to production figures, material has been taken from the reports of the U. S. Geological Survey, cedit for the same being given where used. For production figures in most recent years Prof. Erasmus Haworth, of the Kansas State Geological Survey, has kindly furnished information.

For all assistance thus rendered the authors desire to express appreciation and give full credit.

At different times, work in limited amount of the kind here presented has been done upon Kansas coal. Five samples

were analyzed and tested in the laboratories of the U. S. Geological Survey, now of the Bureau of Mines, all of which samples, however, were taken from the large field in the southeastern part of the state. Volume III of the University Geological Survey of Kansas, published in 1898, dealing entirely with the coal and coal fields, contains records of work done on about forty samples. These samples were taken in a different manner from those taken in the present investigation, and the calorimetry work was not done with apparatus of fully recognized accuracy. Valuable as these records are, they are not in form for as convenient reference as when published separately, and it was necessary to collect a complete new set of samples for the additional and corroborative work. It seemed best, therefore, to omit the former analyses and proceed with the present set of samples independently. It is believed that the results herein published are reliable, and representative of the coal actually on the market from the mines of the state.

UNIVERSITY OF KANSAS.

ENGINEERING EXPERIMENT STATION.

Bulletin No. 3. January, 1913.

KANSAS FUELS: COAL, OIL, GAS.
SULPHUR CONTENT OF BITUMINOUS COAL.

BY

P. F. WALKER, Professor of Mechanical Engineering.
WALTER BOHNSTENGEL, formerly Assistant in Fuel Laboratories.

CONTENTS.

KANSAS FUELS.

SUPPLY.

The fuels of Kansas include coal, petroleum, and natural gas.

The coal-mining industry has been an important one for the past forty years, and at present furnishes employment for about 13,000 men. The amount mined in this period is 2.2 per cent of the total known deposit, and at the average rate of the past five years it will take 762 years to exhaust the supply. The price of the coal has risen gradually, and it is probable that under the stimulus of the various enterprises established in southeastern Kansas during the prevalence of cheap gas during the past ten years, the demand for coal will increase and this industry will experience a growth greater than in the immediately preceding years.

Petroleum products became a factor of importance in the last decade of the nineteenth century, but had its most important development in 1903-1904. Since the latter date the tendency to drop in production is evident, but the past two years show a slight increase over 1910, due to advance in the price paid for crude oil. The prices obtainable in the midcontinental field have been uniformly low in proportion to the value of the stock, and this has kept production down below normal figures.

Natural gas has been produced in the state for more than twenty years, and became an important factor in the years 1902 to 1905. Production continued to increase until 1909, but is now declining rapidly.

Among the states the normal position of Kansas as a coal producer is in tenth place, although in 1910 the production fell to an abnormally low figure because of strikes among the miners. As an oil producer its position was ninth in 1910, and it is likely to pass into eighth place in the near future. As a gas producer it was third in 1909, but has since declined, and figures to determine its exact status are not available.

Table of Fuel Products: Production and Value.

YEAR.	COAL.		OIL.		GAS.	
	Tons.	Value.	Barrels.	Value.	Cubic feet.	Value.
1908..........	6,245,508	$9,292,222	1,801,781	$746,695	80,740,264,000	$7,691,587
1909	6,986,478	10,083,3[illegible]4	1,263,764	491,633	75,074,416,000	8,293,846
1910..........	4,921,451	$7,914,709	1,128,668	$444,763	*..............	....
911.........	6,254,228	9,654,572	1,227,932	626,431	*..............	....

* Not determined for Kansas alone.

EXTENT OF COAL FIELDS.

The following statement is taken from the U. S. Geological Survey Report on the Mineral Resources of the United States for 1910:

"The coal measures of Kansas occupy the eastern portion of that state and underlie approximately 20,000 square miles, of which 15,000 have been estimated as probably more or less productive. The coal measures belong to the Pennsylvania series of the Carboniferous, and include the southwestern extension of the Iowa-Missouri field. The deposits differ somewhat from those of the adjacent states, in that the division between the upper and lower portions is not so well marked. The limestones, which in Iowa and Missouri characterize especially the upper portion of the coal measures, are more prominent in Kansas, and coal is also found to some extent in the upper beds as well as in the lower. The total thickness of the coal measures has been estimated at 3000 feet. The dip is to the north and west, and the beds increase in thickness in that direction. The most important coal field in the State is that of Cherokee and Crawford counties, in the southeastern corner. In this field the Cherokee bed, which varies in thickness from 3 to 10 feet and has a general average of 40 to 42 inches, is largely mined. The coal is of better grade than found in adjacent states, and the mining conditions as regards roof and floor are excellent. Approximately 91 per cent of the output of the State comes from these counties. Some of the coal mined in this district possesses coking qualities, and a small quantity of coke is made from slack coal produced at the mines in the vicinity of Pittsburg. About half of the coal used in coke making is washed before being charged into the ovens. The coke is used by the zinc smelters in and about Pittsburg.

"Some of the coal beds lie very near the surface, and mining operations are carried on by removing the overburden and stripping the coal. Some of this strip-pit coal is used raw in the smelting of zinc, for which purposes its absolute noncoking qualities make it especially adaptable. This fuel is known locally as 'dead coal.'

"The second district of importance is that adjacent to Leavenworth and Atchison, in the northeastern portion of the State, where, at a depth of from 700 to 1150 feet and at horizons equivalent to those mined

in eastern Missouri, a thin bed of coal is found. This field yields a trifle less than 6 per cent of the total output of the State and is notable as being the only point at which deep mining is carried on in the western interior coal field. The third important district in Kansas is that of Osage and adjacent counties, in which a coal bed 20 to 22 inches thick is mined and yields approximately 3 per cent of the State's output. This bed is notable as being well up in the upper coal measures and stratigraphically 2000 feet above the Cherokee coal. It occupies approximately the horizon of the bed locally mined in southwestern Iowa.

"According to the estimates of M. R. Campbell, the total area of Kansas known to contain workable coal beds is 3100 square miles, while the area of which little is known, but which may contain workable coal, is estimated at 15,780 square miles."

The coal fields are crossed and to a large extent developed by the Atchison, Topeka and Santa Fe; Kansas City, Mexico & Orient; Kansas City Southern; Leavenworth, Kansas & Western; Missouri, Kansas & Texas; Missouri Pacific; St. Louis & San Francisco, and Union Pacific railroads.

EXTENT OF OIL FIELDS.

The Kansas oil field is a portion of the so-called midcontinental field, which covers portions of Kansas, Oklahoma and northern Texas. The productive portion lies chiefly in ten counties in the southern and eastern portion of the state, forming a belt extending from northeast to southwest, just west of the principal coal deposits. As fuel for general purposes, outside of gasoline products, it is not of especial importance under present commercial conditions, and is not considered at great length in this bulletin.

EXTENT OF GAS FIELD.

The gas field coincides generally with the oil field, although of slightly greater extent. The product has been of great importance in the development of manufacturing interests of several kinds in the southeastern part of the state, especially in cement, glass and brick plants and in smelters. The supply is becoming exhausted rapidly, however, and it will not long continue as a factor of commercial importance excepting in localized districts.

THE NATURE OF FUEL IN GENERAL.

The particular elements entering into the composition of fuels are carbon and hydrogen. Several other elements are usually present in small quantities, such as nitrogen and oxygen, which are volatilized in combustion, while other solids—noncombustible substances known as ash—are always present in varying quantities. Sulphur is present in many cases, in quantity as high as 6 or 7 per cent by weight in some coal on the market. It has a heat value of 4050 heat units per pound when burned in a dry atmosphere, but it is so objectionable from many viewpoints as a fuel constituent that its presence is undesirable. Government contracts for coal usually specify an upper permissible limit of 5 per cent sulphur for general purposes at land stations. For stoking purposes in the navy much smaller sulphur content is allowed.

Both carbon and hydrogen unite chemically with oxygen with great rapidity when heated, and generate heat in the process. This is known as the process of combustion. Two and one-third pounds of oxygen, or 11.3 pounds of air, are required per pound of carbon for this process, and the heat produced is 14,600 heat units. That is, it would heat 14,600 pounds of pure water one degree Fahrenheit, at or near 60 degrees. With an insufficient supply of oxygen, carbon monoxide gas is formed, producing 4450 heat units. Hydrogen burns to water gas, H_2O, requiring 34.56 pounds of air per pound, and producing 62,000 heat units. This high heat value makes of hydrogen a valuable constituent in fuels. Oxygen in a combined state is often associated with the hydrogen, however, and serves to cut down its available heating value in corresponding proportion. It is universally true that those coals running high in hydrogen content also contain oxygen, so that the presence of large quantities of the volatile gaseous constituents means that after passing a certain limit the increase in heat value due to hydrogen ceases. The exact proportion of volatile gases in the coal which gives the particular combination for a maximum heat value is not a fixed quantity, but is generally in the neighborhood of 18 per cent.

When coal is heated gradually a certain part of it will pass off as a volatile gas before the actual chemical process of com-

bustion begins. These volatile gases include the hydrogen, oxygen and nitrogen, together with hydrocarbon gases, in the forms of marsh gas, olefiant gas, volatilized pitch, etc. The term "volatile matter" is commonly employed to indicate this material. In the furnace the volatile portion burns above the bed of fuel, and in the manufacture of artificial gas it passes without burning directly into the product. The solid fuel remaining is composed of what is termed "fixed carbon," and any solid noncombustible matter which forms a residue or ash. This solid fuel is the coke of commerce, the best qualities of which are made from coal containing small amounts of ash and sulphur.

Petroleum, in its various forms, is a compound of carbon and hydrogen in various proportions, with some oxygen, and is very complex in chemical character. The leading group of hydrogen compounds present in the Kansas petroleum is the paraffine series, having the chemical equation C_nH_{2n+2}. Traces of sulphur may be present, but commonly there is not enough of this element to be especially objectionable. The average proportions of the main elements, as determined by ultimate chemical analysis of a typical sample of Kansas oil, are:

Carbon	85.43 per cent.
Hydrogen	13.07 per cent.
Oxygen	1.00 per cent.
Nitrogen	0.13 per cent.
Sulphur	0.37 per cent.

The natural gas of Kansas and Oklahoma is composed mainly of the hydrocarbon compound known as methane. Its chemical equation is CH_4, and it is commonly known as marsh gas. There is always present nitrogen to the extent of 2 to 5 per cent, and small quantities of several other gases. Complete chemical analysis reveals the presence of several hydrocarbon gases other than CH_4, but their amounts are small and their properties are so nearly the same that no appreciable error is involved in the usual assumption that the entire combustible

portion is methane. The following table of analyses is taken from Engineering Bulletin No. 2 of the present series:

Table of Gas Analyses Made at the University.

DATE.	CH_4.	Other hydro-carbons.	CO.	Total com-bustible.	CO_2.	Oxygen.	Nitrogen.
May 16, 1906..........	98.06	0.0	0.00	98.06	0.20	0.0	1.74
Dec. 23, 1907..........	94.47	Not taken.	0.00	94.47	1.85	Trace.	3.68
Jan. 11, 1910..........	95 20	Not taken.	0.00	95 20	0.80	0.2	3.80
Feb. 1, 1910..........	93.80	Not taken.	0.00	93.80	0.60	0.2	5.40
Mar. 4, 1912..........	91.10	2.4	0.45	93.95	0.40	0.6	5.05

CLASSIFICATION OF COAL.

Coal is classified according to the proportions of volatile gas and fixed carbon contained in the combustible portion. Due to varying causes, the process of distillation of water and volatile substances of the original vegetable fiber during its transformation into the coal has gone on at varying rates in different sections of the country. The combustible portion is that remaining after the weights of moisture and noncombustible ash have been deducted, so that the two items of volatile gases and of fixed carbon may be expressed as percentages of this combustible portion, together forming 100 per cent.

The standard classification in the United States is as follows:

ANTHRACITE: When volatile matter is not more than 7½ per cent of the total combustible.

SEMI-ANTHRACITE: When volatile matter is from 7½ to 12½ per cent of the total combustible.

SEMI-BITUMINOUS: When volatile matter is from 12½ to 25 per cent of the total combustible.

BITUMINOUS: When volatile matter is from 25 to 50 per cent of the total combustible.

LIGNITE: When volatile matter is over 50 per cent of the total combustible.

In physical characteristics, coal from one section of the country may differ considerably from coal which by analysis belongs to the same class but which was mined in another section. A certain general tendency is very noticeable in the distribution of coal over the United States, in that there is a nearly regular gradation from anthracite down the list in passing from the extensive eastern Pennsylvania coal fields westward. Exceptions to that occur in the anthracite coal of

Colorado and the semi-anthracite of Arkansas, but the tendency is clearly evident. In the Mississippi valley bituminous coals only are found, with the exception noted above, and with some lignitic coal in the northern regions of Iowa and Montana. In the Missouri deposits, of which the Kansas coal fields form a part, the coal is in the bituminous class, but usually with comparatively large percentages of volatile gases.

METHODS OF INVESTIGATION.

In the main, the methods followed in the analytical work on coal in the laboratory were those used and recommended by the chemists of the U. S. Geological Survey and Bureau of Mines and by the American Chemical Society. In some instances the practice was varied in unimportant details in order to suit local conditions, but extreme care was taken to preserve the full degree of accuracy.

SAMPLING.

It is recognized that in all work with coal the value of results is directly dependent upon the accuracy with which the sample represents the material being judged by the investigation. It was decided to base the present work on coal actually being delivered to consumers by rail, under the normal conditions of mining. It will be apparent that this differs in some respects from the method of investigating the vein of coal. Investigations of the latter sort express more accurately, it is true, the exact quality of the coal and represent more truly the possibilities of the mine. In the present study, however, the purpose has not been so much a study of the characteristics of coal as it has been a study of the coal available to consumers in the open market. This is the problem met with by the user of fuel, which was the true purpose in view when the work was undertaken. The question of efficiency of mining is involved here, since the elimination of the material from the underlying and overlying strata will bear directly upon the results obtained in analysis. The man who is purchasing coal is not so much concerned with what the mine contains in the form of pure fuel as he is with that fuel which he receives regularly.

In following out this plan all samples were taken at the surface. This was usually done by taking the coal as it was being

dumped from the hoisting cars in the tipple over the screens to cars in the process of loading. From each car hoisted in the mine a small shovelful of coal was taken at random, lumps large and small, and fine slack, all being mixed together for the mine-run samples. As the mining process is carried on, each shift of cars drawn to the base of the shaft at the working levels is made up of cars from the various sections of the mine, only one or two coming from a single room. It was known, therefore, that a composite sample taken from a given number of cars represented somewhat more than one-half as many rooms, and by waiting over the short intervals of time following the hoisting of the cars from one shift, and then continuing sampling from cars coming in from a second shift, another set of rooms in an entirely different quarter of the mine would be represented. This was the practice regularly followed, and in many cases practically every portion of the mine would be represented in the sample taken. This sample, amounting in weight to several hundred pounds in most cases, was then quickly broken down to approximately uniform size and quartered down by the familiar method of dividing the heap of crushed coal into quarters, after thorough mixing, and eliminating the opposite portions, this process of elimination being continued until the sample was down to the capacity of a quart fruit jar, which was then sealed tightly and taken to the laboratory. In a very few instances samples were taken from railroad cars which had been loaded, but in these cases care was taken to work carefully over the car, to dig to different levels, so as to secure a representative body of coal. In every instance where this method was followed it was in a region where samples had been taken by the standard method from mines in the same locality. In several instances, when the standard sample had given a result by analysis different from that which had been expected in the locality, duplicate samples from the same mine were secured at later dates. In most cases where this was done the results of the second analysis substantially corroborated the work on the first sample.

Recognizing the great importance of the sampling of coal, a special effort was made at one mine to determine accurately the differences among samples taken at varying points and in

different manners. To this end, with the aid of several qualified assistants, samples were taken underground by cutting through the vein of coal at the working face, after carefully clearing away the strata above and below, at four different points where the work was progressing regularly in the mine. In each case a V-shaped notch about 6 inches deep was cut through the full depth of the vein and the coal removed carefully and quartered down in the usual manner. At the same time that this was being done, samples were being taken at the surface in the standard manner, with the difference that separate samples were taken from the several grades into which the coal was being screened. These grades were four in number, the first being large lumps passing over the 5½-inch screen, making up 43 per cent of the total coal; the second, "railroad lump," passing through the 5½-inch screen and over the 3½-inch, making up 26 per cent of the coal; the third, egg coal, passing through the 3½-inch screen and over the 2-inch screen, making up 9 per cent of the coal; and the fourth, mixed nut and slack, passing through the 2-inch screen, making up 22 per cent of the coal. By this means a study of the composition of the various grades was possible, showing the manner in which the coal naturally broke, as well as making it possible to use the composite sample in comparison with the several samples taken at the working face of the vein, underground. The results of this appear in the table on page 14.

From the data given above, it will be noted that in the samples taken above ground an increased amount of ash is present, which is a result to be expected. Moisture in the underground samples is greater, the samples being subjected to less air-drying, and it is possible that some other than hygroscopic moisture was present. On the whole, however, comparing the composite sample taken above ground with the average of the four samples cut from the working face of the vein, a remarkable similarity exists. When reduced to the terms of combustible, the percentages are found for volatile gases and fixed carbon respectively to be practically identical. The efficiency of the mining process is also shown by these figures.

As to the varying nature of the coal, based on the gradation according to size of lumps, no very consistent laws are notice-

Proximate Analyses of Special Samples from a Single Mine.

Sample No.	Origin and Grade of Coal Sample.	Sample as taken. Moisture	Sample as taken. Volatile matter	Sample as taken. Fixed carbon	Sample as taken. Ash	Dried sample. Volatile matter	Dried sample. Fixed carbon	Dried sample. Ash	Combustible. Volatile matter	Combustible. Fixed carbon	Sulphur. Sample as taken	Sulphur. Dried sample	Per cent of output
	SURFACE SAMPLES:												
55	Fancy lump, over 5½ in. screen	8.05	32.15	48.40	11.40	34.90	52.65	12.45	39.85	60.15	4.15	4.51	43
56	Railroad lump, over 3½ in., through 5½ in. screen	7.70	31.45	49.55	11.30	34.05	53.65	12.30	38.85	61.15	4.85	5.25	26
59	Egg coal, over 1¼ in., through 3½ in. screen	7.00	30.75	49.20	13.05	33.05	52.90	14.05	38.40	61.60	4.76	5.12	9
65	Nut and slack, through 1¼ in. screen	8.25	29.00	42.40	20.55	31.60	46.00	22.40	40.75	59 25	4.50	4.90	22
	Composite analysis for run of mine	7.90	31.14	47.45	13.51	33.79	51.47	14 74	39 66	60.34	4.46	4.84	100
	MINE SAMPLES:												
57	Room 9, northeast side, 20-in. vein	8.65	32.35	50.20	8.80	35 40	54.95	9.65	39.20	60.80	3.97	4.35	....
60	Room 1, southwest, 20-in. vein	8.15	31.70	49.85	10.30	34.55	54.25	11.20	38 90	61.10	4.30	4.68	....
61	Room 2, northeast side, 20-in. vein	9.00	32.20	47.80	11 00	35.35	52.60	12.05	40.25	59.75	4.78	5.25	....
62	Room 1, northwest, 21-in. vein	9.10	31.55	47.75	11.60	34.75	52.50	12.75	32.80	60.20	4.79	5.27	....
	Average of mine samples	8.75	31.95	48.90	10.40	35.02	53.56	11.42	39 54	60.46	4.46	4.89	....

able. There is a tendency for the fixed carbon to become less in the smaller grades and a very noticeable increase in the ash occurs in the slack. Evidently the sulphur-bearing seams, present to excess in a portion of the vein, are so spaced as to cause the breaking of the coal into medium-size lumps, the sulphur adhering to these lumps and appearing in greater percentage in the samples. It is clear that the sulphur is not in excess in the noncombustible portions, since the high ash content of the slack is accompanied by a comparatively small amount of sulphur. The mine thus sampled is in the Leavenworth district, and there is no evidence to show that similar conditions exist in other regions. The purpose of this special brief investigation was to demonstrate the accuracy of the sampling method employed.

Samples were taken from the three important coal districts in the state, which districts have been described in the section above headed "Extent of Coal Fields." In the largest district, mainly in Crawford and Cherokee counties, thirty-four mines were sampled. In the Leavenworth, Kan., region, where the coal is all taken from a small number of comparatively large mines, four samples were taken, one of these being the state mine, represented by several separate analyses made on coal used regularly in the State University plant. In the Osage county district sixteen mines were sampled, this number being comparatively large in proportion to the amount of coal mined.

The accompanying map, following page 40, shows the location of these mines, the number given corresponding to the number of the sample occurring in the tabulated list of the results.

PREPARATION OF SAMPLE.

The entire sample, consisting of the contents of a full quart fruit jar, was brought sealed to the laboratory and there crushed in an iron crusher of the coffee-mill type, down to a size passing a 10-mesh sieve. After thorough mixing, this was quartered down by the usual method until about two ounces remained. This reduced sample then became the laboratory sample on which all subsequent work was done.

Considerable attention was given to the further preparation of this small sample. When ground to a fineness sufficient to

pass a 100-mesh sieve, so much time is usually required that air-drying is likely to cause a considerable reduction in the moisture content. The first grinding and general handling of the sample is sufficient to remove all surface or mine moisture, so that in this final grinding it seems clear that there is an actual loss of hygroscopic moisture. A quicker grinding of the two-ounce sample in a pulverizer, however, brings it to a condition where a considerable portion will pass the 100-mesh sieve, and all would pass a 60-mesh sieve. With samples prepared in these two ways, several comparative moisture determinations were made, and it was decided that, on the whole, the quickly ground but unsieved coal gave results more reliable in the item of moisture, and fully as accurate in all other determinations, including the combustion for heat value in the calorimeter. The latter method was therefore adopted as the standard method throughout the course of the investigation.

APPROXIMATE ANALYSIS.

Moisture Determination.

Exactly one gram of coal in each instance was weighed into a crucible on a standard analytical balance, and then placed in the usual form of drying oven heated by gas flame to a temperature of about 220 degrees Fahrenheit. One hour was the time regularly allowed for the drying process, although some experimenting was done here to determine whether a longer or shorter time would give better results. It was found, however, that one hour gave substantially the same results as longer periods, so that no change was made from the usually recognized practice. Other experiments with different temperatures led the authors to the opinion that a variation of 10 to 20 degrees above 220 is not sufficient to cause any loss of volatile gases; but, on the other hand, there is nothing gained in using these higher temperatures. The time of one hour seems to be approximately the time required to drive from the particles of coal all hygroscopic moisture, and with the higher temperatures mentioned there is increasing danger of slight oxidation of carbon at the surface of the mass in the crucible.

Volatile Matter.

In determining volatile matter the method followed was to take the sample just dried and weighed to determine moisture, with a close-fitting cover over the crucible, and place it over a Bunsen flame for seven minutes. The gas used was the natural gas from the midcontinental field, and best results were found by placing the crucible from six to eight centimeters above the top of the burner. When burning free this gas would burn with a flame about twenty centimeters high.

During the first few minutes of this process, beginning as soon as the coal became heated to a dull red, the gases passing off burned with a smoky flame upon issuing from the covered crucible. Toward the end of the period this burning ceased, at which time the crucible and coal within would be at a brilliant red heat. Experimenting at this point to determine whether all of the gases were driven off at the time when flaming ceased, indicated that this would not be true in all cases, and the more appropriate method proved to be that of giving the sample the full period of seven minutes for the driving out of all volatile gaseous matter. It seems evident that different grades of coal require different methods of treatment in this respect, some yielding consistent results when the distillation is stopped when the flame disappears, while other coals, particularly those higher in volatile matter, continue to distill gases after burning ceases. Undoubtedly this is due to the larger nitrogen content of these volatile coals.

Fixed Carbon.

In determining the fixed carbon it is necessary to burn either the same sample used for the above determinations, or a newly weighed one-gram sample of green coal, entirely to the ash residue. Practice differs between these two methods, due mainly to existing conditions controlling the rapidity of the process. In the present investigation both methods were used, but for the larger portion of the samples the remaining quantity of coke, after the completion of the distillation of the volatile matter, was brought back to the blast burner and the carbon burned off directly in the open crucible. In order to facilitate this process a special brick oven was constructed, confining the heat in a high degree, so that several samples could be burned simultaneously under conditions of extremely

high temperature. Since much of the coal is of the noncoking variety, this method was generally as expeditious as is the method of burning the green coal sample directly. Usually half an hour was sufficient to burn the sample to constant weight.

In this final weighing, as was also true in the weighing for moisture and volatile matter, the crucible was cooled to normal temperature in desiccators, employing calcium chloride for the absorption of atmospheric moisture. The differences obtained between these weighings give the four desired quantities. When running samples in large numbers this method of procedure is found to keep the operator employed continuously and is as expeditious as any method possible.

PRESENTATION OF RESULTS.

In the tables giving the results of the analytical work on coal, the analyses are stated in terms of percentage by weight of the total amount of material included in the determination. This is first done with the full 100 per cent value standing for the original sample as it came from the mine. In the table it is given under the heading of "Moist Coal." The analysis shows all of the four quantities determined; namely, moisture, volatile matter, fixed carbon, and ash.

Due to the fact that in the handling of individual samples in the laboratory, or to any peculiar conditions under which the sample might have been taken, the moisture content is likely to vary and to be different from that of the same coal when delivered for use under any given conditions. Since the moisture determination is readily made, it often becomes of value to know how a properly dried sample would analyze. For this reason a second set of results is shown, consisting of the three items; volatile matter, fixed carbon, and ash. It will be observed that these latter quantities are determined by dividing the corresponding quantities in the first analysis by one, minus the percentage of moisture.

For purposes of comparison it is very desirable that the analysis of the coal when entirely free from moisture and noncombustible ash be known. For scientific purposes this statement of the analysis is of great value, in that it shows the exact status of the coal according to standard classification.

Only the two items, volatile matter and fixed carbon, appear in this statement which occurs in the table under the heading "Combustible." The values here given are determined by dividing the corresponding original values by the quantity remaining when the weights of moisture and ash are deducted from an original unit sample.

In the same table occurs the heat value of the coal as determined by calorimetric test, and it will be observed that this quantity is expressed on the same basis as are the approximate analysis results.

Sulphur content is expressed in terms of moist coal and dry coal only. The present investigation did not enter into the question of the condition of the sulphur content. It may be assumed that it is all combustible, but no special value attaches to its expression in terms of the combustible portion of the coal alone.

It will be observed that the coal from the central Kansas district, in Osage and adjoining counties, is shown to be materially different from the other coals. Particularly does it differ from the general average of the coal from southern Kansas, which latter is the distinctive coal region of the state. This may best be seen by noting the percentage of volatile matter under the heading of "Combustible," where it will be observed that for the central Kansas coals this quantity runs uniformly above 40 per cent. In no case does the coal from southern Kansas show over 39 per cent of volatile matter, and only in occasional instances is that value exceeded in the Leavenworth district. This difference may be explained by the fact, stated in another part of this bulletin, that the Osage county coal field is well up in the upper coal measures and stratigraphically 2000 feet above the coal of the southern Kansas field. The Leavenworth coal, while lying much deeper below the surface at the point where mined than are the veins at both of the other coal districts, stands between the other two in classification based on percentage of volatile matter. Stratigraphically and by analysis it is closer to the southern Kansas coal.

HEATING VALUES.

The heating values of all solid and liquid fuels have been determined by direct combustion in the Mahler bomb calorimeter of standard design, constructed by L. Golaz, in Paris,

France. The oxygen used in the combustion was secured from the Linde Air Products Company, of Buffalo, N. Y. It is purchased in tanks under heavy pressure, so that it may be run into the calorimeter bomb directly, facilitating the work of the process in great measure.

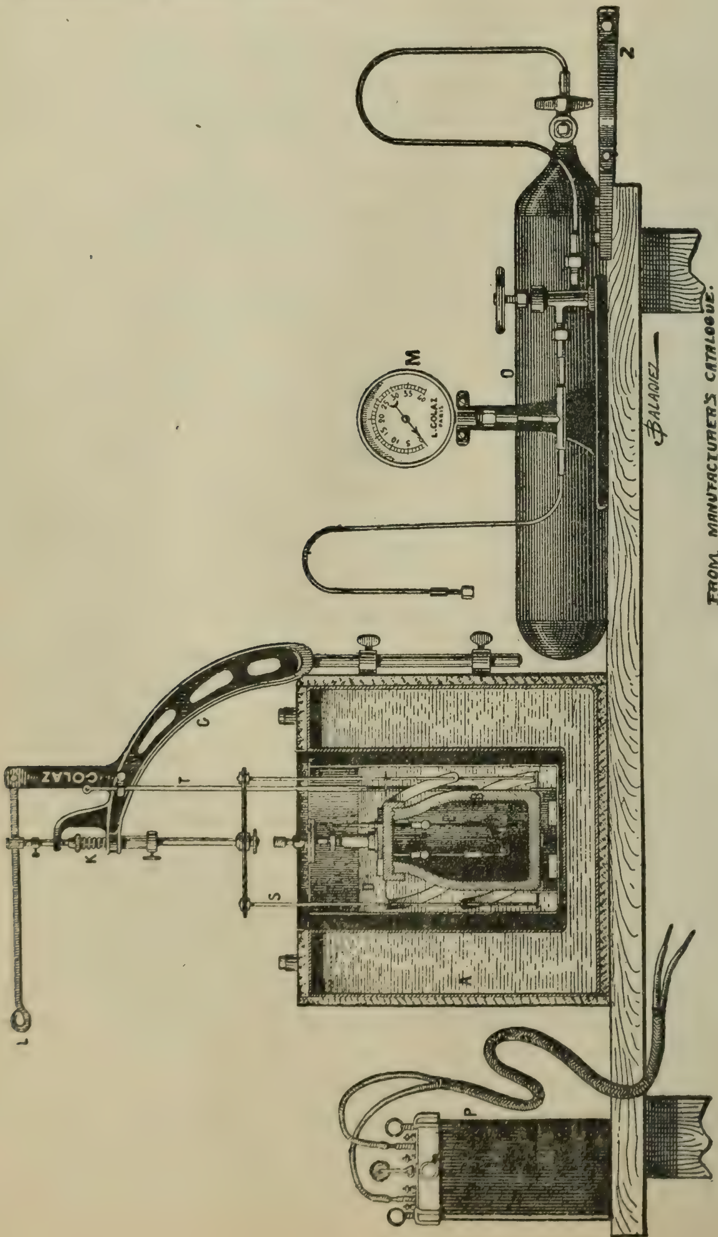


FIG. 1. Section of Calorimeter.

Description of Apparatus.

In brief description as to construction and use, the instrument consists of the following parts:

A heavy steel bomb, porcelain lined, of about 550 cubic centimeters capacity, fitted with screwed cap. This cap terminates above in a central standard about 10 centimeters high, hollow, fitted with a needle valve operated by a milled handpiece, and through which the oxygen is admitted and the generated gases of combustion discharged. Inside the cap are attached two platinum wires extending about half way to the bottom of the bomb, one having metallic contact and the other passing through an insulated opening for electrical connection above. One of these wires supports the platinum tray in which the fuel, carefully weighed, is placed, and across the lower ends of the two is passed a piece of fine iron fuse wire of determined weight, so looped as to touch the fuel. This wire should be such that a current of two amperes will fuse it quickly, its function being to ignite the fuel. In the presence of the compressed oxygen, a pressure of from 18 to 25 atmospheres being employed, combustion of both wire and fuel is extremely rapid, and, in order to withstand the exceeding high pressure produced, the bomb and all its connected parts must be constructed with wide safety margins and handled with great care. The cap screws down to a lead gasket set in a groove to prevent blowing out, the surfaces of which must be carefully watched and protected from scratches. The needle valve is comparatively soft, to seat itself under reasonable pressure applied on the screw, and must be kept in good condition by occasional dressing with a round, fine file. The cap is likely to stick in the heavy threads and be difficult of removal after a combustion, and to remedy this condition ordinary vaseline may be used sparingly as a lubricant. Care must be exercised to keep all lubricant outside the lead gasket, and to leave uncontaminated the rinsings of the bomb used for sulphur determination.

A copper cylindrical pail or bucket, large enough to contain the assembled bomb, together with 2200 to 2400 cubic centimeters of distilled water and affording space around the bomb for the copper agitator. The water must entirely cover the

bomb and cap proper, leaving projecting above the surface the insulated platinum wire and the central standard which is used as the other pole.

An insulated covering, consisting of a double-walled cylindrical vessel containing in the annular space water at proper temperature. The inner diameter of the cylinder is sufficient to receive freely the copper water bucket, and the height is somewhat greater than the depth of water in the bucket. This latter precaution serves to maintain a condition of uniform temperature immediately above the exposed water surface, unaffected by sudden variations in the room, and places the entire mass of water employed as a heat absorbent more directly under the controlling influence of the water-jacketed insulator. The water bucket is supported on a wood triangle in the bottom of the cylindrical compartment, so that it is surrounded entirely by an atmosphere of air in close contact with the insulating covering.

Supported in bearings on the side of the outer cylinder is a curved standard, supporting the stirring mechanism over the center of bomb and cylinder and the thermometer suspended in the water close beside the bomb.

The thermometer is divided in fiftieths of a degree centigrade, can be read directly to hundredths, and, by magnifying glass, the operator can estimate thousandths of a degree. It is certified by the standard standardizing inspectors at Paris.

Other parts, for handling and operating, consist of pressure gauge and operating valves for the oxygen connection, clamping vise for the bomb, wrenches, etc.

Principles of Operation.

In preparing a sample of coal for combustion, some authorities hold to the method of compressing the finely ground particles into briquettes. The main purpose of this is to prevent loss of dust particles after weighing, and scattering inside the bomb under the impact produced at the ignition, which may occur very suddenly. Comparative investigations along this line have failed in revealing any such effects, and the authors have become satisfied that the weighing into the platinum tray of the powdered particles is a method reliable within all possible limits of observations. This method has, accordingly, been followed throughout the work with coal.

In operation, certain general principles must be understood. In the atmosphere of oxygen in the bomb, provided a sufficient amount is present, the fuel burns completely. That is, carbon burns directly to CO_2 and hydrogen to H_2O with full liberation of heat. The heat is utilized in raising the temperature of the water in the copper bucket immediately surrounding the bomb, and the temperature of the bomb itself and all other parts of the apparatus directly in contact with the water. The influence of this mass at increased temperature upon the surrounding atmosphere and other bodies, or, we may say, the counter influence of those surrounding substances on the masses being directly heated, is small, and is accounted for by methods for correcting the observed rise in temperature of the water. These methods are discussed at some length in the following pages.

It is clear that in order to make effective the full amount of heat liberated in the chemical process of combustion, the gaseous products must be cooled down to the initial temperature. Since the preparation of the material is best carried out at room temperature, this means cooling back to a like temperature, which is accomplished substantially by making the quantity of heat-absorbing material, mostly water, large in proportion to the amount of heat generated. As the process is regularly carried out, the increase in temperature is but from 2.0 degrees to about 4.0 degrees Centigrade for fuels ranging from coal of 10,000 heat units to oils of 20,000. Since the gases confined in the bomb pass through temperature ranges of several thousand degrees, this small variation amounts to but a small fraction of one per cent, which is well within the limits of error in observation.

With fuels containing hydrogen another element enters here, in that the recooling of the gases condenses the superheated water vapor to liquid form. At the same time, moisture in the coal, hygroscopic or otherwise, is first evaporated and then condensed. The latent heat released by this condensation from hydrogen combustion is thus registered as a part of the heat value of the fuel, although it is not effective in raising the temperature of the gaseous products of combustion. For this reason, in many cases where products of combustion are used at temperatures never falling to the con-

densing point, it is customary to deduct the value of this latent heat from the quantity determined by the calorimeter method, and to call the difference the "available" heating value. There is an inconsistency in making this single correction, since in the actual case the heat represented by the difference in temperature of the gaseous products when finally discharged and of the fuel and air when mixed in the furnace is also not "available." The latent heat is by far the largest item, however, and practice sanctions the method. An attendant result of this condensation of water vapor, both from hydrogen combustion and inherent moisture, is the presence of moisture in the bomb and resultant chemical activity, in a manner discussed in the following paragraphs.

Inside the bomb, before the cap is screwed down, is nitrogen of the air. As a part of the volatile gases of the fuel there may be a small additional amount of nitrogen. This amount of nitrogen, with water and excess of oxygen, forms nitric acid in accordance with the equation

$$2H_2O + 2N_2 + 5O_2 = 4HNO_3$$

This reaction is accompanied by the generation of heat, and since it can not occur during combustion in the usual dry furnace atmosphere, a correction must be made by subtracting the amount of the heat formed. The amount to deduct is determined by titrating the bomb rinsings with a standard alkali solution of sodium carbonate, Na_2CO_3. For convenience in operation, the strength of the solution is made such that each cubic centimeter of the solution required to overcome the acidity of the rinsings shall represent one calorie, the metric unit of heat being used, since all observations are made on that basis. To accomplish this, since the heat of formation of nitric acid is 227 calories per gram, each c.c. of the solution must contain enough sodium carbonate to offset $1/227$, or 0.0044 grams of the acid. By the laws for neutralization of acids, it follows that the amount of sodium carbonate necessary is 3.706 grams per liter, thus fixing the strength of the standard solution.

The second chemical change brought about by the presence of moisture in the bomb is the burning of the sulphur of the fuel to sulphuric acid instead of to sulphur dioxide. The latter combustion is the one which normally takes place in the dry

furnace, and in it heat is generated at the rate of 2250 calories per gram of sulphur. When burned to acid, however, 2230 additional calories are generated per gram of sulphur while the titration requires more of the sodium carbonate solution to neutralize all acid in the rinsings, and each c.c. is counted as one calorie out, on the basis of all acid present being nitric. Each c.c. of the alkaline solution is equivalent to 0.00108 gram of sulphur in sulphuric acid, or to $0.00108 \times 2230 = 2.41$ calories of this excess heat. One calorie has been deducted on the basis of nitric acid, leaving 1.41 calories more to be deducted for each c.c. of the sodium carbonate solution. This means a correction of ${}^{1.41}/_{0.00108} = 1306$ calories per gram of sulphur, or 13.06 calories for each per cent of sulphur in the fuel. When the percentage of sulphur has been determined, all that remains is to multiply the result by 13.06 and deduct the value so found from the apparent heat value in calories, after the so-called sodium carbonate titration figure has been similarly deducted. In a succeeding chapter of this bulletin the probable relative values of sulphur percentage and the amount of standard sodium carbonate solution used in titration will be discussed, from which it will be seen that an estimate of sulphur may be made from the titration result, sufficiently accurate for the heat-value correction in commercial work, the probable error becoming not more than one tenth of one per cent.

One important matter underlying accurate calorimetry work consists in the proper regulation of temperatures of water in the jacket and around the bomb of the instrument, and the finding of the proper corrections to be applied to the observed rise in temperature of water during combustion. Since this corrected temperature rise is to be multiplied by the weight of water around the bomb plus water equivalent of the calorimeter parts, a total quantity of 2700 grams according to the method followed in the present instance, it follows that an error in temperature readings and corrections will be multiplied by 2700. The need for care is obvious. The corrections often amount to 20 or more thousandths, representing 60 or more calories, or over 100 B. t. u.

Under usual conditions the water used around the bomb is at a lower temperature than the atmosphere in immediate

contact with it and its containing copper bucket, this atmosphere being controlled artificially by the water-jacketed covering. It is desirable that it should be so, since during combustion its temperature will be raised, and if, in its final condition, it be as much warmer than the atmosphere as it was cooler before, the heat losses incident to radiation will be largely nullified. In any case, however, there would remain the question of temperature correction during the period of combustion, when there is a varying rising temperature.

To determine the influence of the atmosphere it becomes necessary, after the bomb has been placed in the water and time allowed for all to average at a common temperature, to wait several minutes, reading the thermometer at each minute interval, in order to find the rate of increasing temperature. Five minutes are usually allowed for this. The preliminary period passed and the weighed sample of fuel ignited exactly at the end of the last minute, it is seen that, until the temperature has risen materially by heat of combustion, some temperature rise is due to atmospheric influence, and hence that a certain negative correction must be made. On the other hand, after the water temperature has risen above that of the atmosphere, a loss outward occurs, the amount of which must be determined by a series of five readings, beginning as soon as the water temperature has reached its maximum and begins to fall. This is known as the final period. During the first part of the combustion period it is necessary to read temperature after the lapse of the first half minute following ignition, in order to fix the rate of increase. If it begins promptly and runs up steadily for the whole of the first minute, one method should be used. If it starts slowly with small increase for a half minute, then mounts quickly during the next period, a somewhat different method should be used, as will appear immediately. If the hand stirring apparatus is used, care should be taken to secure uniform motion.

The record of observation should be preserved in regular form, the following being that employed in the Kansas laboratory:

Preliminary period.	Combustion period.	Final period.
0 ... 25.98	5 ... 26.08	8 ... 28.44
1 ... 26.00	5½ ... 26.50	9 ... 28.43
2 ... 26.03	6 ... 27.80	10 ... 28.42
3 ... 26.05	7 ... 28.40	11 ... 28.42
4 ... 26.07	8 ... 28.44	12 ... 28.41
5 ... 26.08		13 ... 28.41

Total rise 0.10
Rise per min.............. 0.020
Observed rise during combustion............. 2.36
Total fall during final period.............................. 0.030
Fall per minute.. 0.006

In developing the methods for making corrections to the observed temperature rise, reference may be made to the accompanying illustration (Fig. 2), where the observations during combustion are shown in different form. On the right of the central line are shown actual readings and differences. On the left are the rates of change, the values 0.020 at the 5th minute, and 0.006 at the 8th minute, being those determined as shown above, the latter being a negative increase. Since at the 7th minute the temperature is essentially the same as at the 8th, it may be assumed safely that the temperature effect of the surrounding atmosphere is the same, so that 0.006 is assigned to that minute. This closeness of temperature reading is almost sure to exist at the minute preceding the maximum record, the maximum being sometimes at a 9th minute, occasionally at the 7th, but usually at the 8th. At the 6th minute the rate is an unknown quantity, but is expressed as differing from 0.020 by an amount "x." Similarly, "y" represents the variation at half-minute interval, 5½.

The two following methods of treatment are approximate only, with different degrees of accuracy. They are based on the assumption of uniform rate of temperature rise during isolated minute or half-minute intervals. It is possible to treat the problem with mathematical exactness, but it will be shown that the errors involved in the case are not sufficient to warrant the labor involved.

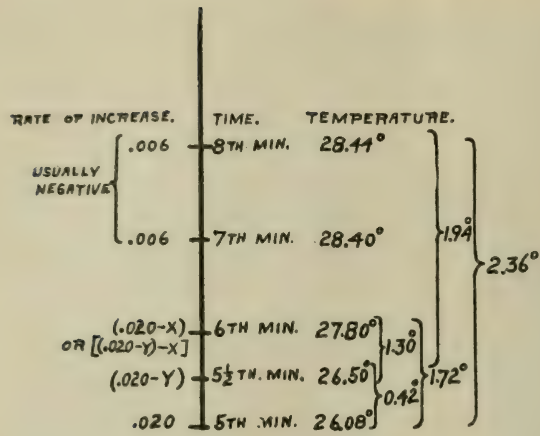


FIG. 2. TEMPERATURE RECORD DURING COMBUSTION PERIOD, SHOWING ATMOSPHERIC INFLUENCE.

Using the numerical values of Fig. 2, and making use of the half-minute reading, we may write the proportion:

$$\frac{\text{Change of rate, 5th to } 5\tfrac{1}{2}\text{th}}{\text{Change of rate, 5th to 8th}} = \frac{\text{Change of temperature, 5th to } 5\tfrac{1}{2}\text{th.}}{\text{Change of temperature, 5th to 8th.}}$$

$$\text{or,} \quad \frac{y}{[\,.020-(-.006)\,]} = \frac{0.42}{2.36}$$

$$\text{from which } y = 0.0046$$

Hence "the rate of increase" at '5½' = 0.020 — 0.0046 = .0154°.

Similarly for the half minute, 5½ to 6:

$$\frac{x}{[\,.0154-(-.006)\,]} = \frac{1.30}{1.94}$$

$$\text{or, } x = .011$$

from which "rate of increase" at "6" = 0.0154 — .011 = 0.0044°.

It should be observed here that the maximum temperature of 28.44° is not much above that of the surrounding atmosphere. Had the initial temperature of the water been closer to that of the atmosphere the "rates of increase" at the 5th and 8th minutes would have been more nearly equal, numerically, and at the 6th minute the "rate of increase" would probably be negative. This bears upon a point already men-

tioned, that the temperature at the beginning should be as much below that of the atmosphere as at the end it is above.

Knowing the "rate of increase" at each division point, we may now find the amount of correction for each interval of time, on the basis of average over a period of uniform rise of temperature, as follows:

$$\text{Increase of temperature during 5 to } 5\tfrac{1}{2} = \frac{0.020 + 0.0154}{2} \times \frac{1}{2} = 0.00885^\circ$$

$$\text{Increase of temperature during } 5\tfrac{1}{2} \text{ to 6} = \frac{0.0154 + 0.0044}{2} \times \frac{1}{2} = 0.00495^\circ$$

$$\text{Increase of temperature during 6 to 7} = \frac{0.0044 + (-0.006)}{2} = -0.0008^\circ$$

$$\text{Increase of temperature during 7 to 8} = \ldots\ldots\ldots\ldots = -0.0060^\circ$$

$$\text{Increase of temperature during 5 to 8, net total,} = +0.0070^\circ$$

That is, the water of the calorimeter has increased in temperature by 0.007° due to atmospheric influences, and the net temperature rise due to the heat of combustion of fuel is

$$2.36 - 0.007 = 2.353^\circ.$$

This is the corrected temperature rise, which multiplied by the weight of water in grams, gives the amount of heat generated in the bomb.

In the second method we will omit consideration of the half-minute reading at '5½,' assuming uniform rate of temperature rise from 5 to 6. Our proportion then becomes

$$\frac{x}{[.020 - (-.006)]} = \frac{1.72}{2.36}$$
$$x = .019.$$

"Rate of increase" at 6 = .020 — .019 = .001°.

We then have

$$\text{Increase of temperature during 5 to 6} = \frac{0.020 + .001}{2} = 0.0105^\circ$$

$$\text{Increase of temperature during 5 to 7} = \frac{0.001 + (-0.006)}{2} = -0.0025^\circ$$

$$\text{Increase of temperature during 7 to 8} = \ldots\ldots\ldots\ldots = -0.0060^\circ$$

$$\text{Increase of temperature during 5 to 8, net total,} = 0.0120^\circ$$

The corrected temperature rise on this basis then is

$$2.36 - 0.012 = 2.348^\circ.$$

With water temperatures more evenly divided above and below the atmosphere, the net total increase is usually negative, when it will be added to the observed temperature rise.

Of the two methods the first, obviously, is the more accurate. The difference amounts to 0.005°, or $2700 \times 0.005 = 13.5$ calories. The total heat generated is $2700 \times 2.353 = 6353.1$ calories. The difference of 13.5 calories thus amounts to 0.212 per cent, or to about one-fifth of one per cent. This is not a large error, and when the reading at the 5½th minute is such as to indicate a more uniform increase from 5th to 6th, it is permissible to use the shorter method. It was the method used in much of the present work. It is observed that the total correction of 0.007° amounts in this case to but one-third of one per cent, but under usual conditions of temperature range it is a larger quantity, and applied in the opposite direction as above noted. The amount by which this value of 0.007° is in error, as compared with an absolutely correct solution, is less than the probable errors of observation and measurement.

In following out the calculation partially indicated above, the sample of coal giving the readings was ignited with a weight of 0.01 gram of iron wire; the titration for nitric acid required 47 c.c. of the sodium carbonate solution; and the analysis showed 4.8 per cent sulphur. The corrections for heat generated thus become

For wire	$0.01 \times 1650 = 16.5$	calories.
For nitric acid	47.0	"
For sulphur	$4.8 \times 13.06 = 62.7$	"
Total	126.2	"

Corrected heat value $= 6353.1 - 126.2 = 6226.9$ calories per gram,
$= 6226.9 \times 1.8 = 11208.4$ B. t. u. per lb.

The sample was from a coal containing 7.5 per cent moisture, so that the heat value per pound of dry coal becomes

$$11208.4 \div 0.925 = 12125 \text{ B. t. u.}$$

WATER EQUIVALENT OF CALORIMETER PARTS.

In the sample calculation of heating value from the calorimeter observations, given on page 26, there appears an item representing the effect of those portions of the apparatus which are immersed, and which must conform in temperature to the water. Since this is an item of about 500 grams, to be

multiplied by a corrected temperature of from two to four, it is seen that it must be correct to within a few numbers in units place in order to come within the limits of accuracy determined by the other work. Considerable attention has been given to its determination.

The water equivalent of the instrument may be obtained by different methods:

First, by the weights and specific heats of the parts, the water equivalent of the instrument may be calculated. This method was followed out as carefully as conditions would permit, it being impossible, however, to separate entirely some of the platinum and porcelain weights from steel, mercury from glass in the thermometer, etc., and a value was obtained of 536 grams of water. The experimental values show this value to be somewhat high.

Second, by the addition of a measured quantity of water at a known temperature to a quantity of water in the calorimeter at a different temperature, where the value of the calorimeter enters as an unknown quantity it can be calculated from the resulting temperature. This method, however, is not very satisfactory, on account of the inevitable loss or gain of heat while pouring the water from one vessel into another. In order to compensate these losses in a measure, it was decided to keep the water in the calorimeter initially at room temperature, and have the water that was poured in for the first trial a number of degrees above, and at the next trial the same number of degrees below, room temperature.

Third, by proportion. This is the most reliable and satisfactory method involving the use of a substance of known heat value. A definite quantity of substance (charcoal in this case) was burned in the bomb, using first a minimum amount of water—that is, just enough to cover the bomb—and then a maximum amount, or as much as the calorimeter bucket would contain. This permitted a difference of 600 grams of water and gave a satisfactory proportion where the water equivalent of the instrument entered as the quantity "x," an unknown. The following is a sample determination:

	Max. water.	Min. water.
Weight of fuel	1.0 gram	1.0 gram
Corrected temperature rise	2.227° C.	2.745° C.
Weight of water	2700. grams	2100. grams

Extra weight of bomb cap immersed with maximum water, multiplied by specific heat of steel = 14 calories equivalent.

$$\text{Then } 2.227(2700+x) - 14 = 2.745(2100+x)$$
$$.518\,x = 6012.9 - 5764.5 + 14 = 262.4$$
$$x = 507 \text{ grams} = \text{water equivalent of instrument.}$$

The average results of twenty-six determinations by these various methods gave the water equivalent of the instrument as 500 grams. This value was used in the calculations of all the heat values of the coals here given.

HEATING VALUE OF OILS.

The calorimetry work on oils, when they are sufficiently heavy to make evaporation losses while weighing the sample negligible, is no different from that on coal. Only traces of sulphur are found, usually. Volatile oils must be run into thin glass bulbs, which are then sealed and weighed, the bulb being broken in the closed bomb by shaking. The volatile hydrocarbons produce tremendous and sudden pressures in the bomb if used in the one-gram size of sample common with coal, and hence it is wise to use but appoximately one-half gram, with which lower oxygen pressure is permissible. Fifteen atmospheres are sufficient for that weight of combustible, twenty-four or twenty-five being necessary for a full gram of the heavy oils, and eighteen sufficient for common bituminous coal with its high ash and moisture content.

In the accompanying table are given the heating values of twenty-four different crude oils, representing the oil fields of the state. They are arranged in order of density, and it will be noted that this does not accord with geographical distribution, both heavy and light oils occurring in many counties.

In addition to the work with the several crude oils, it has been the purpose to study the characteristics of the various grades given off in the process of fractional distillation. To this end, No. 19, an oil close to the average density, was subjected to the distillation process on a 50-degree interval basis, beginning at 150°. That is, all light distillates passing off at a temperature of 150° Centigrade were condensed, a sample preserved of the distillates and another of the residue left in the still. The temperature was then raised 50 degrees and another pair of samples taken, and so on to the limit. The results of tests on these samples are given in the table with the crude

oils, under the headings of "Fuel Oil": "Residues" and "Distillates." The first distillate corresponds roughly to the light naphthas, the second to gasoline, and the third and fourth combined to kerosene. Remaining distillates in the lubricating and polishing classes, which do not split sharply on temperatures, are grouped together as being "heavier than kerosene." Under "Fuel Oil" are listed three oils whose exact origin is unknown, they being oils found by the author in use at as many power plants in the state. These, with No. 3 and No. 4 residue, represent so-called "Fuel Oil" as it has been on the market in the past years.

TABLE OF HEATING VALUES OF KANSAS CRUDE OILS.

No.	Sample from county of	Sp. grav. at 25° C.	Density, Baume.	Heat value per lb. B. t. u.
1	Wilson	.8378	37.1	20915
2	Montgomery	.8413	36.4	19070
3	Chautauqua	.8465	35.4	20490
4	"	.8473	35.2	19744
5	"	.8525	34.2	19577
6	Miami	.8556	34.0	20125
7	"	.8573	33.3	19455
8	Montgomery	.8590	33.0	20085
9	Miami	.8593	32.9	20410
10	Montgomery	.8601	32.8	19500
11	Chautauqua	.8801	32.3	18480
12	Montgomery	.8604	32.7	19200
13	Allen	.8623	32.4	19400
14	Neosho	.8639	32.0	20645
15	Montgomery	.8640	31.9	19510
16	"	.8660	31.6	20630
17	Neosho	.8674	32.4	18670
18	Montgomery	.8706	30.8	19600
19	Neosho	.8722	30.5	19749
20	Allen	.8749	30.0	19530
21	Montgomery	.9030	24.7	19290
22	"	.9110	23.7	17105
23	Wilson	.9340	21.5	18750
24	Coffey	.9340	19.7	19550
	Average, crude oil,	.8692	31.1	19530

FUEL OILS.

Residue from Crude Oil No. 19.

1	Distilled at 150° C.,	.8730	29.5	19720
2	" " 200° C.,	.8870	27.4	19670
3	" " 350° C.,	.9010	25.0	19606
4	" " 370° C.,	.9250	21.6	19513

Commercial Oils from Miscellaneous Sources.

5	....	.8790	29.4	19186
6	....	.8870	27.4	19565
7	....	.8950	26.8	19630
	Average of last five..	.8970		19500

DISTILLATES, FROM CRUDE OIL NO. 19.

	Sp. grav. at 25° C.	Density. Baume.	Heat value per lb. B. t. u.
At 150° C. and below..	.7275	....	22020
From 150° to 200°...	.7705	....	21900
From 200° to 250°...	.8060	....	21300
From 250° to 300°..,	.8317	....	20700
Mean distillates heavier than kerosene	.8600	....	20500

HEATING VALUE OF NATURAL GAS.

The following is given to meet any possible interest in the question, not as representing direct experimental work in heating values, but as calculations from analyses, based on the known calorific values of the constituents. Much of the gas concerned came from Oklahoma, and it represents the midcontinental gas field rather than Kansas. The analyses given in the table on page 10 were all of gas drawn from the pipe line at Lawrence, thus being composite samples from scores of wells scattered through southern Kansas and northern Oklahoma.

For all ordinary commercial work it is sufficiently accurate to consider the entire combustible portion of the gas as methane. The small quantities of other hydrocarbons, differing but little in unit values from methane, and the extremely small amount of carbon monoxide, are not nearly as potent in affecting the value of the gas as are the influences of temperature and pressures, as these properties fluctuate in service with small notice taken by the user. We are thus concerned simply with the properties of pure methane and the percentage of combustible in the gas.

Methane has a heat value of 23,600 British thermal units per pound. At a pressure of four ounces above standard atmospheric pressure and at 60 degrees Fahrenheit a cubic foot of methane gas weighs 0.043 pound, and thus has a heating value of nearly 1015 heat units. Natural gas containing 93 per cent combustible thus may be considered as having a heat value of 945, and so on. For every degree of temperature of gas below 60 degrees the heat value increases nearly two units. For each additional ounce of pressure the value increases by about four units, or for each additional inch of water pressure by about 2.3 units. With these figures at

hand, the change of heat value for minor variations in pressure and temperature may be estimated within a fraction of one per cent error, it being understood that variations in atmospheric pressure must be corrected for, as well as in the observed pressure above atmosphere.

SULPHUR IN BITUMINOUS COAL FROM THE KANSAS-MISSOURI BASIN.

By WALTER BOHNSTENGEL.

SULPHUR DETERMINATION.

When the Mahler bomb calorimeter is used in determining the heat value of coals, it is a simple matter to make a sulphur determination, because the sulphur is oxidized to sulphate and may be precipitated and weighed as barium sulphate.

After firing a sample of coal in the bomb, it is necessary that all the sulphuric acid formed be rinsed into a beaker in order to obtain a true analysis. It has been found that it requires eight to ten rinsings with distilled water, of 15 to 20 c.c. each, to do this. In order to clean the solution of ash and dirt, it is convenient and expedient to pour the rinsings from the bomb through a filter into the beaker. While this order may be varied to suit the convenience of the operator, it is apparent that time may be saved by handling it but once. There should be 200 to 300 c.c of solution.

After titrating with sodium carbonate for the heat value of nitric acid, the solution is acidified by adding one or two c.c. of concentrated hydrochloric acid, or enough to make it decidedly acid. This is indicated by the returning of the color originally imparted to the rinsings by the addition of methyl orange, before titration. It is then put on the hot plate, allowed to come to boiling, then a liberal excess of barium chloride is added slowly, with constant stirring, this barium solution being prepared in accordance with the instructions contained in a following paragraph, and being heated to a corresponding temperature with the acidified rinsings to which it is added. The mixture is allowed to stand on the hot plate just below the boiling point for an hour or so, or until the precipitate of barium sul-

phate settles out quickly. After this the clear solution is poured through a washed filter, or a Gooch filter, allowing the precipitate to remain in the bottom of the beaker. This precipitate is then washed several times by decantation and transferred to the filter, and washed with hot water until free from chlorides. The wash water may be tested for chlorides with a drop of silver nitrate. The filter is then transferred to a weighed crucible, dried, and then burned over a blast burner to constant weight. A second weighing gives, by difference, the weight of barium sulphate, from which the sulphur is found by multiplying by 0.1373, as seen from the following:

Barium sulphate is made up of the following parts by weight:

Barium	137.4
Sulphur	32.06
Oxygen (four)	64.0
Total	233.46

Then sulphur equals 32.06 divided by 233.46, which equals 0.1373, or 13.73 per cent.

Barium Chloride Solution: A solution of barium chloride containing 20 grams of barium chloride to the liter gives the following results: 137.4 (combining weight of barium) divided by 244.3 (combining weight of barium chloride) equals 56.2 per cent barium in barium chloride; or 20 times 0.562 equals 11.24 grams of barium available. In barium sulphate the sulphur equals 32.06 divided by 137.4, or 23.35 per cent of the barium; or 1000 c.c. of barium chloride solution is sufficient to precipitate 11.24×0.2335 or 2.62 grams of sulphur. Hence a coal containing five per cent of sulphur will require nearly 20 c.c. of the above solution for complete precipitation.

A liberal excess of barium chloride does no harm, while an insufficient amount means inaccuracy or extra work; hence it is advisable to add an excess of 50 to 100 per cent over the probable calculations. This means an addition of 30 to 40 c.c. of the solution to the filtrate, and a proportional increase in the amount of time required to filter; hence it is more desirable to use a stronger solution of barium chloride, 30 to 50 grams to the liter being preferable, and add a smaller quantity, about 20 c.c., to precipitate the sulphate.

The washings from the calorimeter were used in the regular

sulphur determinations throughout this work, and were checked in a few cases by means of the Eschka method. The results are recorded with the heat values in the main table of results.

SULPHUR BY ESCHKA METHOD.

(Journal American Chemical Society.)

Eschka's method is recommended for most accurate work. The following directions, which are given for the convenience of those using this report, are those by G. L. Heath, with slight modifications:

Mix thoroughly one gram of the finely powdered coal with one gram of magnesium oxide and one-half gram of dry sodium carbonate, in a thin platinum dish having a capacity of 75 to 100 c.c. A crucible may be used, but a dish is preferred. The magnesium oxide should be light and porous, not a compact, heavy variety.

The dish is heated on a triangle over an alcohol lamp, held in the hand at first. Gas must not be used, because of the sulphur it contains. The mixture is frequently stirred with a platinum wire, and the heat is raised very slowly, especially with soft coals. The flame is kept in motion and barely touching the dish, at first, till strong glowing has ceased, and is then increased gradually till in fifteen minutes the bottom of the dish is at a low red heat. When the carbon is burned, transfer the mass to a beaker and rinse the dish, using about 50 c.c. of water. Add 15 c.c. of saturated bromine water and boil for five minutes. Allow it to settle, decant through a filter, boil a second and third time with 30 c.c. of water, and wash till the filtrate gives only a slight opalescence with silver nitrate and nitric acid. The volume of the filtrate should be about 200 c.c. Add 1½ c.c. of concentrated hydrochloric acid, or a corresponding amount of dilute acid (8 c. of acid of 8 per cent). Boil till the bromine is expelled, and add to the hot solution, drop by drop, especially at first, and with constant stirring, 10 c.c. of a 10 per cent solution of barium chloride. Digest on the water bath or over a low flame, with occasional stirring, till the precipitate settles clear quickly. Filter and wash, using either a Gooch crucible or a paper filter. The latter may be ignited moist in a platinum crucible, using a low flame until the carbon is burned.

In the case of coals containing much pyrites or calcium sulphate, the residue of magnesium oxide should be dissolved in hydrochloric acid and the solution tested for sulphuric acid.

If desirable, the burning of the coal with Eschka's mixture may be carried on in a muffle, from 20 to 30 minutes being required.

ESTIMATION OF SULPHUR FROM TITRATION WITH SODIUM CARBONATE.

The need for a correction to the apparent heat value, on account of the formation of nitric acid, has been shown. This is done by titrating with a solution of sodium carbonate.

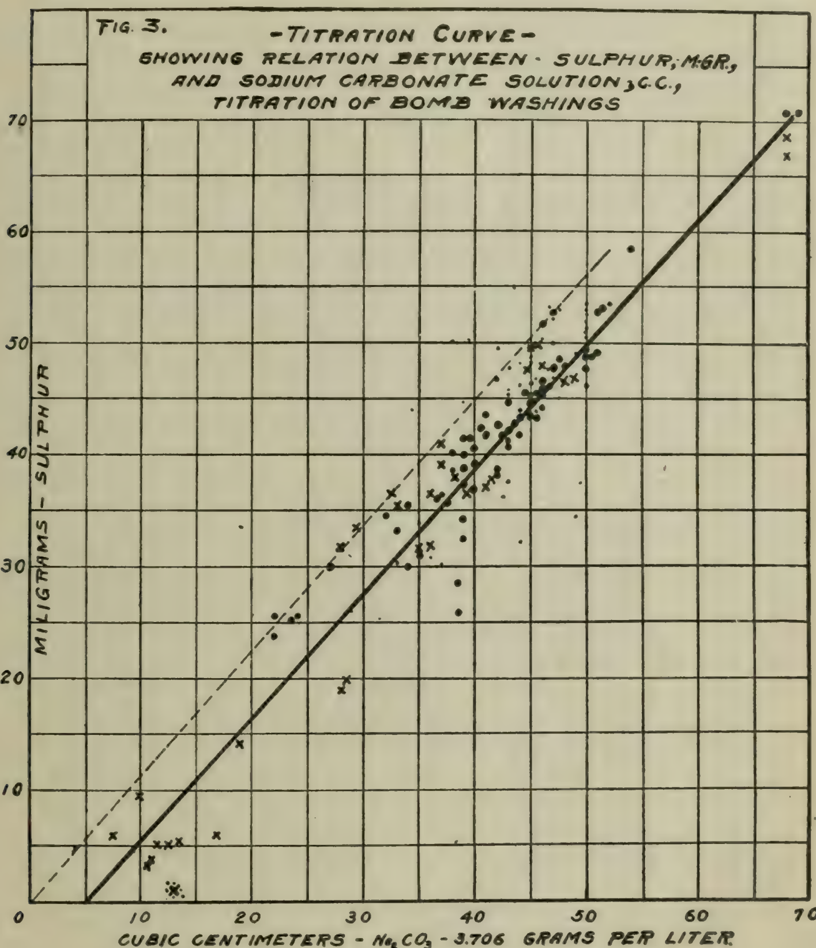
Sodium carbonate was used because it is most convenient for the engineer. A definite amount of chemically pure Na_2CO_3 may be weighed out, and the resulting solution used, where most of the other alkaline reagents would have to be standardized by a process that often requires more time than the analyst wishes to spend. It is not to be understood that a sodium carbonate solution having a certain amount of chemical by weight is an absolute standard, but for the purpose involved the results are well within the experimental errors.

The former discussion also showed that only a part of the alkaline solution was used in neutralizing nitric acid, the remainder being for sulphuric acid formed.

On the accompanying diagram (Fig. 3), the number of cubic centimeters of sodium carbonate solution used in each of many determinations has been plotted as ordinate, and the amount of sulphur contained in the washings, as determined gravimetrically, is shown as abscina. This was done with the view of getting the total heat correction for both nitric and sulphuric acids by merely titrating the washings, thus avoiding the need of a gravimetric sulphur determination when only the heat value of the fuel is desired.

The dotted curve is based on the chemical relation of sodium carbonate to sulphur as sulphuric acid. Then 50 c.c. of the solution used are equivalent to approximately 56 miligrams of sulphur as sulphuric acid, establishing the slope of the line which represents the relation with no nitric acid at all. The empirical curve is the heavy line to the right, and nearly parallel to the theoretical. The horizontal space between

means that a certain amount of the solution (5 to 12 cubic centimeters) is required to neutralize the nitric acid formed, while the remainder is required for the sulphuric acid.



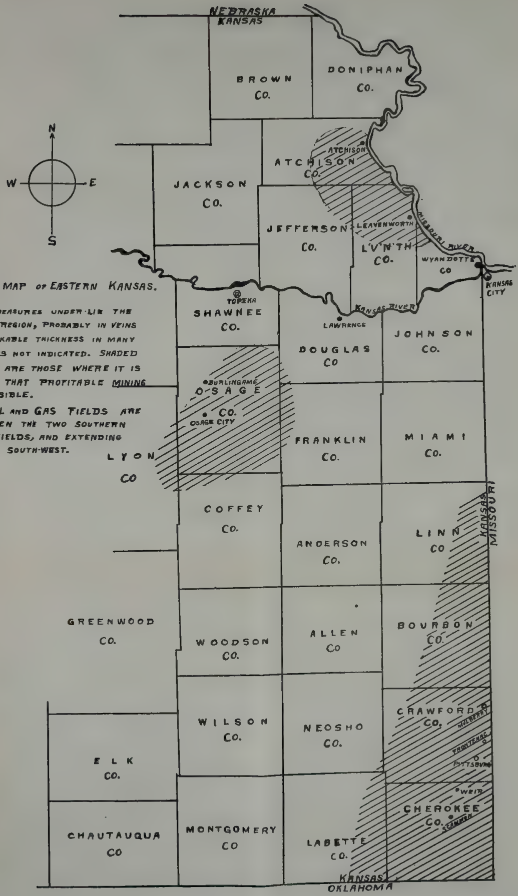
From these curves it is seen that the amount of the heat correction due to both nitric and sulphuric acid may be estimated from the titration values, with results that are well within the limits of experimental errors of the heat determination. The method is illustrated as follows:

Coal No. 15, in the main table of values, required for neutralization of the acids in rinsings, 42.5 c.c. of the alkaline

solution. From the empirical curve in Fig. 3, this corresponds to about 41.5 miligrams, or 4.15 per cent, of sulphur. The heat correction is 4.15 times 13.06, or 54.3 calories. By direct method the sulphur per cent is 4.05, and the heat correction 53 calories. The difference is immaterial from the standpoint of heat value.

The method of making this correction by direct calculation has been shown and discussed in preceding sections of this bulletin.

The variation of the points shows the probable error in finding the true amount of sulphur. It is seen that the actual sulphur in the coal, from the curve, would be subject to considerable per cent variation, depending largely on different coals, but the resulting heat value correction is influenced by a much smaller proportion, and the curve has been found to be very helpful.



LINE MAP OF EASTERN KANSAS.
COAL MEASURES UNDER-LIE THE ENTIRE REGION, PROBABLY IN VEINS OF WORKABLE THICKNESS IN MANY PORTIONS NOT INDICATED. SHADED AREAS ARE THOSE WHERE IT IS KNOWN THAT PROFITABLE MINING IS POSSIBLE.
THE OIL AND GAS FIELDS ARE BETWEEN THE TWO SOUTHERN COAL FIELDS, AND EXTENDING TO THE SOUTH-WEST.
NEBRASKA
KANSAS
N
W
E
S
BROWN CO.
DONIPHAN CO.
ATCHISON
ATCHISON CO.
JACKSON CO.
JEFFERSON CO.
LEAVENWORTH
L'V'N'TH CO.
MISSOURI RIVER
WYANDOTTE CO
KANSAS CITY
TOPEKA
SHAWNEE CO.
KANSAS RIVER
LAWRENCE
DOUGLAS CO
JOHNSON CO.
BURLINGAME
OSAGE CO.
OSAGE CITY
LYON CO
FRANKLIN CO.
MIAMI CO.
COFFEY CO.
ANDERSON CO.
LINN CO
KANSAS
MISSOURI
GREENWOOD CO.
WOODSON CO.
ALLEN Co
BOURBON CO.
ELK CO.
WILSON CO.
NEOSHO CO.
CRAWFORD CO.
MULBERRY
FRONTENAC
PITTSBURG
WEIR
CHEROKEE CO.
SCAMMON
CHAUTAUQUA CO
MONTGOMERY CO
LABETTE CO.
KANSAS
OKLAHOMA

COAL ANALYSIS

UNIVERSITY OF KANSAS.

DETERMINATIONS AND CALCULATIONS

-BY-

Lawrence Kansas 1910-11. WALTER BOHNSTENGEL.

No.	Heat Value. B.T.U.'s Per Pound.			Per Cent Combustible in Moist Coal	Proximate Analysis. Values in Per Cent													Sulphur Per Cent.		Na_2CO_3 c.c. per gram coal	Remarks.	
					Moist Coal					Dry Coal.				Combustible.								
	Moist Coal	Dry Coal.	Combustible		Moisture	Volatile Matter	Fixed Carbon	Ash	Total.	Volatile Matter	Fixed Carbon	Ash	Total	Volatile Matter	Fixed Carbon	Total.	Moist Coal	Dry Coal.		Numbers indicate duplicate samples	Locality.
					SOUTHERN					KANSAS				COALS.								
1.	13385	13675	14740	90.80	2.20	34.15	56.75	6.90	100.00	34.95	58.00	7.05	100.00	37.60	62.40	100.00	2.65	2.71	38.5		Pittsburg.
2.	12710	13220	14850	85.60	3.90	29.50	56.10	10.50	100.00	30.70	58.30	11.00	100.00	34.50	65.50	100.00	3.58	3.72	39.5	See Nº 27.	Scammon.
3.	13030	13195	14320	90.95	1.30	33.50	57.45	7.75	100.00	33.95	58.20	7.85	100.00	36.85	63.15	100.00	3.02	3.05	34.5		Weir City Junction.
4.	12945	13195	14320	90.35	2.00	32.85	57.50	7.65	100.00	33.50	58.70	7.80	100.00	36.40	63.60	100.00	3.28	3.34	39.0		Fleming.
5.	13015	13175	14400	90.25	1.20	32.15	58.10	8.55	100.00	32.50	58.85	8.65	100.00	35.70	64.30	100.00	4.76	4.82	50.0		Frontenac.
6.	12880	13030	14440	89.10	1.15	31.90	57.20	9.75	100.00	32.25	57.85	9.90	100.00	35.75	64.25	100.00	3.70	3.75	37.5		Fleming
7.	12845	12995	14340	89.65	1.10	31.70	57.95	9.25	100.00	32.00	58.65	9.35	100.00	35.35	64.65	100.00	4.06	4.11	43.0		Scammon.
8.	12765	12940	14130	90.30	1.45	29.85	60.45	8.25	100.00	30.35	61.30	8.35	100.00	33.05	66.95	100.00	3.79	3.85	42.0	See Nº 32.	Frontenac.
9.	12505	12655	14210	88.00	1.25	31.10	56.90	10.75	100.00	31.50	57.60	10.90	100.00	35.30	64.70	100.00	4.32	4.38	46.0		Scammon.
10.	12230	12650	14680	83.25	2.55	27.65	55.60	14.20	100.00	28.40	57.00	14.60	100.00	33.20	66.80	100.00	3.41	3.50	33.0	See Nº 25.	Scammon.
11.	12105	12570	14630	82.75	3.70	29.50	53.25	13.55	100.00	30.60	55.30	14.10	100.00	35.60	64.40	100.00	4.16	4.33	43.0	See Nº 34.	Weir
12.	12235	12550	13950	87.75	1.75	32.50	55.25	10.50	100.00	33.05	56.25	10.70	100.00	37.05	62.95	100.00	4.01	4.08	38.5		Scammon.
13.	12335	12535	14060	87.75	1.65	33.80	53.95	10.60	100.00	34.40	54.85	10.75	100.00	38.60	61.40	100.00	4.83	4.91	50.5		Humble
14.	12155	12495	14830	81.90	2.75	28.60	53.30	15.35	100.00	29.35	54.80	15.85	100.00	34.90	65.10	100.00	4.56	4.68	47.0	See Nº 31.	Frontenac.
15.	11970	12480	14660	81.60	4.10	28.40	53.20	14.30	100.00	29.60	55.55	14.85	100.00	34.80	65.20	100.00	4.05	4.23	42.5	See Nº 29.	Pittsburg South
16.	12210	12365	13900	87.80	1.30	31.20	56.60	10.90	100.00	31.60	57.35	11.05	100.00	35.50	64.50	100.00	6.98	7.07	68.5		Fleming
17.	12120	12260	14340	84.45	1.15	31.00	53.45	14.40	100.00	31.40	54.10	14.50	100.00	36.70	63.30	100.00	4.48	4.54	45.0		Scammon.
18.	12050	12175	14230	84.70	1.05	32.05	52.65	14.25	100.00	32.40	53.20	14.40	100.00	37.85	62.15	100.00	4.81	4.86	49.0		Pittsburg South
19.	11970	12115	14260	83.95	1.25	29.55	54.40	14.80	100.00	29.95	55.05	15.00	100.00	35.20	64.80	100.00	4.17	4.23	43.0		Fleming.
20.	11495	12090	14700	78.05	4.95	27.55	50.50	17.00	100.00	29.00	53.20	17.80	100.00	35.30	64.70	100.00	5.29	5.56	51.0	See Nº 30.	Scammon
21.	11910	12085	13900	85.70	1.50	30.75	54.95	12.80	100.00	31.20	55.80	13.00	100.00	35.85	64.15	100.00	4.27	4.33	44.5	See Nº 24.	Frontenac
22.	11895	12065	14500	81.90	1.40	29.90	52.00	16.70	100.00	30.30	52.75	16.95	100.00	36.50	63.50	100.00	3.98	4.03	39.5		Mulberry
23.	11790	12015	13860	85.00	1.90	33.75	51.25	13.10	100.00	34.45	52.25	13.30	100.00	39.70	60.30	100.00	4.42	4.51	45.0		Scammon
24.	11820	11975	14170	83.40	1.25	30.60	52.80	15.35	100.00	31.00	53.45	15.55	100.00	36.70	63.30	100.00	5.22	5.29	51.0	See Nº 21.	Frontenac
25.	11800	11965	13950	84.60	1.40	31.40	53.20	14.00	100.00	31.80	53.95	14.25	100.00	37.10	62.90	100.00	4.62	4.69	46.5	See Nº 10.	Scammon
26.	11770	11905	13660	86.10	1.15	31.55	54.55	12.75	100.00	31.95	55.15	12.90	100.00	36.65	63.35	100.00	3.85	3.90	39.5		Weir City
27.	11565	11790	14100	82.00	1.90	29.75	52.25	16.10	100.00	30.30	53.25	16.45	100.00	36.30	63.70	100.00	3.55	3.61	37.5	See Nº 2.	Scammon
28.	11535	11690	14340	80.35	1.40	28.30	52.05	18.25	100.00	28.75	52.75	18.50	100.00	35.20	64.80	100.00	4.30	4.36	41.0		Fleming
29.	11275	11465	13950	80.70	1.65	30.70	50.00	17.65	100.00	31.20	50.85	17.95	100.00	38.05	61.95	100.00	4.48	4.56	46.0	See Nº 15.	Pittsburg South
30.	11025	11175	13850	79.60	1.40	28.80	50.80	19.00	100.00	29.30	51.40	19.30	100.00	36.30	63.70	100.00	4.15	4.21	41.5	See Nº 20.	Scammon
31.	11050	11160	14040	78.65	1.00	29.10	49.55	20.35	100.00	29.35	50.10	20.55	100.00	37.00	63.00	100.00	4.14	4.18	39.0	See Nº 14.	Frontenac
32.	10930	11070	13890	78.75	1.25	28.90	49.85	20.00	100.00	29.30	50.45	20.25	100.00	36.70	63.30	100.00	4.19	4.24	40.0	See Nº 8.	Frontenac
33.	10150	10325	14160	71.65	1.70	26.75	44.90	26.65	100.00	27.25	45.65	27.10	100.00	37.35	62.65	100.00	2.49	2.53	23.5		Fleming
34.	9935	10080	14000	70.80	1.40	28.15	42.65	27.80	100.00	28.60	43.20	28.20	100.00	39.80	60.20	100.00	2.42	2.46	22.0	See Nº 11.	Weir. Sample from loaded car.
					CENTRAL					KANSAS				Coals								
35.	11245	11995	12930	87.00	6.25	35.20	51.80	6.75	100.00	37.55	56.25	7.20	100.00	40.40	59.60	100.00	3.14	3.35	45.0		Fostoria.

28.	11535	11690	14340	80.55	1.40	28.30	52.05	18.25	100.00	28.75	52.75	18.50	100.00	35.20	64.80	100.00	4.50	4.56	41.0	FLEMING
29.	11275	11465	13950	80.70	1.65	30.70	50.00	17.65	100.00	31.20	50.85	17.95	100.00	38.05	61.95	100.00	4.48	4.56	46.0	See № 15. PITTSBURG SOUTH
30.	11025	11175	13850	79.60	1.40	28.80	50.80	19.00	100.00	29.30	51.40	19.30	100.00	36.30	63.70	100.00	4.15	4.21	41.5	See № 20. SCAMMON
31.	11050	11160	14040	78.65	1.00	29.10	49.55	20.35	100.00	29.35	50.10	20.55	100.00	37.00	63.00	100.00	4.14	4.18	39.0	See № 14. FRONTENAC
32.	10930	11070	13890	78.75	1.25	28.90	49.85	20.00	100.00	29.30	50.45	20.25	100.00	36.70	63.30	100.00	4.19	4.24	40.0	See № 8. FRONTENAC
33.	10150	10325	14160	71.65	1.70	26.75	44.90	26.65	100.00	27.25	45.65	27.10	100.00	37.35	62.65	100.00	2.49	2.53	23.5	FLEMING
34.	9935	10080	14000	70.80	1.40	28.15	42.65	27.80	100.00	28.60	43.20	28.20	100.00	39.80	60.20	100.00	2.42	2.46	22.0	See № 11. WEIR SAMPLE FROM LOADED CAR.
					CENTRAL KANSAS COALS															
35.	11245	11995	12930	87.00	6.25	35.20	51.80	6.75	100.00	37.55	55.25	7.20	100.00	40.40	59.60	100.00	3.14	3.35	45.0	FOSTORIA.
36.	11160	11980	12960	86.05	6.75	36.90	49.15	7.20	100.00	39.60	52.70	7.70	100.00	42.90	57.10	100.00	3.43	3.67	43.0	OSAGE CITY.
37.	11120	11790	12860	86.50	5.60	36.50	50.00	7.90	100.00	38.70	52.95	8.35	100.00	42.20	57.80	100.00	4.80	5.09	50.0	FOSTORIA.
38.	10940	11730	12710	86.10	6.70	35.65	50.45	7.20	100.00	38.25	54.05	7.70	100.00	41.40	58.60	100.00	4.33	4.65	46.0	BURLINGAME.
39.	10905	11630	12760	85.45	6.25	36.00	49.45	8.30	100.00	38.45	52.70	8.85	100.00	42.15	57.85	100.00	4.74	5.06	44.5	"
40.	11015	11620	12830	85.85	5.15	37.25	48.60	9.00	100.00	39.30	51.25	9.45	100.00	43.40	56.60	100.00	4.48	4.73	47.0	"
41.	10645	11535	12670	84.05	7.75	36.00	48.05	8.20	100.00	39.05	52.05	8.90	100.00	42.80	57.20	100.00	4.34	4.73	44.0	OSAGE CITY.
42.	10930	11520	12870	84.95	5.10	36.85	48.10	9.95	100.00	38.80	50.75	10.45	100.00	43.40	56.60	100.00	5.02	5.30	51.0	FOSTORIA.
43.	10650	11495	12780	83.30	7.45	35.90	47.50	9.15	100.00	38.80	51.35	9.85	100.00	43.00	57.00	100.00	3.59	3.88	39.5	OSAGE CITY.
44.	10620	11440	12790	83.00	7.15	34.25	48.75	9.85	100.00	36.95	52.50	10.55	100.00	41.30	58.70	100.00	4.22	4.55	43.0	FOSTORIA
45.	10465	11370	12730	82.15	8.00	30.80	51.35	9.85	100.00	33.50	55.80	10.70	100.00	37.50	62.50	100.00	4.44	4.82	45.0	OSAGE CITY
46.	10590	11365	12550	84.30	6.95	35.25	49.05	8.75	100.00	37.90	52.70	9.40	100.00	41.80	58.20	100.00	4.87	5.24	50.0	FOSTORIA.
47.	10515	11335	12560	83.65	7.30	33.70	39.95	9.05	100.00	36.35	53.90	9.75	100.00	40.30	59.70	100.00	2.90	3.12	38.5	BURLINGAME
48.	10565	11225	12630	83.55	5.90	35.00	48.55	10.55	100.00	37.15	51.65	11.20	100.00	41.90	58.10	100.00	4.57	4.85	45.0	"
49.	10365	11220	12320	84.05	7.65	34.90	49.15	8.30	100.00	37.85	53.20	8.95	100.00	41.55	58.45	100.00	3.32	3.60	49.0	OSAGE CITY.
50.	10215	11050	12440	82.05	7.50	32.45	49.60	10.45	100.00	35.10	53.65	11.25	100.00	39.50	60.50	100.00	4.09	4.42	46.0	OSAGE CITY.
51.	9650	10325	12000	80.40	6.50	36.20	44.20	13.10	100.00	38.65	47.30	14.05	100.00	45.05	54.95	100.00	6.09	6.52	59.0	BURLINGAME.
					LEAVENWORTH COALS.															
52.	13300	13655	14580	91.20	2.60	37.75	53.45	6.20	100.00	38.75	54.85	6.40	100.00	41.40	58.60	100.00	2.97	3.05	36.5	HAND PICKED SAMPLES.
53.	13250	13515	14580	90.90	1.90	37.90	53.00	7.20	100.00	38.60	54.05	7.35	100.00	41.70	58.30	100.00	2.49	2.56	30.5	NOT REPRESENTATIVE.
54.	11695	12675	14560	80.25	7.75	31.45	48.80	12.00	100.00	34.10	52.90	13.00	100.00	39.10	60.90	100.00	4.27	4.63	39.0	
55.	11647	12663	14450	80.55	8.05	32.15	48.40	11.40	100.00	34.90	52.65	12.45	100.00	39.85	60.15	100.00	4.15	4.51	35.7	
56.	11670	12640	14400	81.00	7.70	31.45	49.55	11.30	100.00	34.05	53.65	12.30	100.00	38.85	61.15	100.00	4.85	5.25	41.5	
57.A.	11500	12590	13930	82.55	8.65	32.35	50.20	8.80	100.00	35.40	54.95	9.65	100.00	39.20	60.80	100.00	3.97	4.35	42.0	A · Fine Ground.
57.B.	11750	12630	13940	84.30	6.90	32.35	51.95	8.80	100.00	34.75	55.80	9.45	100.00	38.40	61.60	100.00	4.06	4.36	45.0	B - Sifted · 100 mesh.
58.	11385	12475	14370	79.10	8.80	30.85	48.25	12.10	100.00	33.90	52.90	13.20	100.00	39.05	60.95	100.00	4.94	5.40	45.0	
59.	11365	12215	14200	79.95	7.00	30.75	49.20	13.05	100.00	33.05	52.90	14.05	100.00	38.40	61.60	100.00	4.76	5.12	41.0	
60.A.	11260	12250	13800	81.55	8.15	31.70	49.85	10.30	100.00	34.55	54.25	11.20	100.00	38.90	61.10	100.00	4.30	4.68	45.5	FOR EXPLANATION OF
60.B.	11210	12130	13810	81.05	7.65	31.40	49.65	11.30	100.00	34.00	53.75	12.25	100.00	38.70	61.30	100.00	4.70	5.09	47.0	SAMPLES 55, 56, 57, 59,
61.A	11070	12160	13840	80.00	9.00	32.20	47.80	11.00	100.00	35.35	52.60	12.05	100.00	40.25	59.75	100.00	4.78	5.25	48.0	60, 61, 62, AND 65, SEE REPORT ON "SPECIAL
61.B.	11110	12030	13620	81.50	7.60	32.30	49.20	10.90	100.00	35.00	53.25	11.75	100.00	39.65	60.35	100.00	4.82	5.22	47.0	SAMPLES FROM A
62.A.	10960	12040	13810	79.30	9.10	31.55	47.75	11.60	100.00	34.75	52.50	12.75	100.00	39.80	60.20	100.00	4.79	5.27	47.0	SINGLE MINE" IN
62.B.	11050	11960	13720	80.50	7.60	32.70	47.80	11.90	100.00	35.40	51.75	12.85	100.00	40.70	59.30	100.00	4.89	5.29	48.5	THE PRECEEDING PAGES.
63.	11475	11830	13740	83.50	2.95	35.30	48.20	13.55	100.00	36.40	49.65	13.95	100.00	42.30	57.70	100.00	4.80	4.95	50.0	
64.	11460	11810	13580	84.35	3.00	33.65	50.70	12.65	100.00	34.70	52.25	13.05	100.00	39.85	60.15	100.00	4.95	5.11	50.0	64, 66, AND 67 ARE SAMPLES FROM MINE-RUN
65.	10220	11130	14340	71.20	8.25	29.00	42.20	20.55	100.00	31.60	46.00	22.40	100.00	40.75	59.25	100.00	4.50	4.90	40.0	COAL DELIVERED TO
66.	10070	10380	12730	79.10	3.05	33.35	45.75	17.85	100.00	34.40	47.20	18.40	100.00	42.20	57.80	100.00	4.66	4.81	44.0	UNIVERSITY FROM STATE
67.	9975	10370	12840	77.30	3.80	31.50	45.80	18.90	100.00	32.75	47.60	19.65	100.00	40.75	59.25	100.00	5.14	5.34	50.0	PENITENTIARY MINE. LANSING.

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ENGINEERING BULLETIN No. 4.

Part I.—The Organization and Work of the Engineering Experiment Station of the University of Kansas.

Part II.—Vocational Education in Kansas, with Courses of Study Now Offered by the University School of Engineering.

BY

GEORGE C. SHAAD

AND

P. F. WALKER.

UNIVERSITY ENGINEERING EXPERIMENT STATION.

LAWRENCE, KANSAS.

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of Engineering Departments.

The Station designs to issue bulletins, of which this is the fourth number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

THE UNIVERSITY OF KANSAS.

ENGINEERING EXPERIMENT STATION.

BULLETIN NO. 4. OCTOBER, 1913.

PART I. THE ORGANIZATION AND WORK OF THE ENGINEERING EXPERIMENT STATION OF THE UNIVERSITY OF KANSAS.

By GEORGE C. SHAAD, Professor of Electrical Engineering.

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The Organization and Work of the Engineering Experiment Station of the University of Kansas.

I. INTRODUCTION.

All of the important engineering schools, in addition to their teaching work, carry on some scientific investigations along engineering lines with a view to publishing the results of such investigations, either in the scientific or technical press, the transactions of engineering societies, or in special bulletins issued by the school or the university with which the school is connected. Through such publications the results are made available to others who may have occasion to use them. In some schools work of this nature is done by the various departments working independently, with or without some special organizations within the separate departments for the carrying out of such independent investigations. In other cases a step further is taken in organization and the engineering school acts more as a unit in promoting special investigations, and the school may employ men to devote a large portion or all of their time to research work. Finally, there are the schools in which engineering experiment stations are established, and the establishment of these stations is, in the main, but a step further in the organization of the school for the accomplishment of the greatest amount of good to the state or community through the agency of special engineering investigations.

The work along the lines of special investigations which are undertaken by the engineering schools, whether through the agency of the organization of an engineering experiment station or not, which is for the general benefit of the state, or the community, or engineering at large, must be distinguished from other important work of a more private nature which is often undertaken by the schools by agreement with individuals or corporations. Work of the latter nature is paid for by the individuals or corporations, and the reports are not made public unless the parties for whom the work is done wish them to be.

Engineering experiment stations, then, have been organized in several of the technical schools in the United States with the purposes, in the main, as follows: to correlate and sys-

tematically group together the results of scientific investigations as they are conducted under the various departments of the schools; to plan, organize, and direct additional work to be carried out by the departments of the school along lines which will be of practical benefit to engineers in general and to the state or the locality in which the school is situated in particular; to act in stimulating and elevating the engineering education given by the school; and to arrange for the publication and distribution of the results of engineering and industrial research work. The engineering experiment station differs from the agricultural experiment station in that its problems are of an engineering nature, and, as yet, no act providing for federal aid to engineering experiment stations organized in land-grant colleges has been passed by Congress. Some engineering stations have secured federal aid for the carrying out of special investigations, but such aid has not been very general.

The organization of an engineering experiment station for the purpose of directing and carrying on the work of special engineering investigations has been carried out in a number of schools, and, in addition to the one at the University of Kansas, may be mentioned the University of Illinois, the Iowa State College, the Kansas State Agricultural College, the University of Missouri, the Pennsylvania State College, the University of Ohio, and the University of Utah School of Mines.

In some of the institutions separate appropriations are made for carrying on the work of the experiment station, and several men are employed to devote their entire time to special investigations, while in other schools the expense for the work is borne largely by the particular departments in which the work is carried on, and the appropriations for the departments are made with such expenses in view. Members of the regular instructional force devote some time to work of the experiment station, and they may be relieved of teaching work to a certain extent so that they may have time to devote to research. Research fellowships serve to bring many to these stations who are well equipped to carry on the work.

The technical schools of the country are especially adapted to the carrying on of organized investigations along engineering lines on account of the fact that they possess extensive and superior equipment and the teaching staff is composed of engineers particularly well qualified to direct scientific inves-

tigations with a view to the practical application of the results of such work. Again, the reports coming from these schools are entirely unbiased and the institutions may use their publishing and distribution facilities for the placing of the results of investigations before all who may be in a position to profit by them.

II. PARTIAL LIST OF SUBJECTS UPON WHICH BULLETINS HAVE BEEN ISSUED.

With such facilities it is not surprising to find authoritative publications issued by engineering experiment stations, or by the separate departments of the schools where the station organization is lacking, covering a large variety of practical engineering topics, among which, as illustrations, may be mentioned:

CONCRETE CONSTRUCTION.

THE ECONOMICAL DESIGN OF REINFORCED CONCRETE BEAMS:
Engineering Experiment Station,
School of Mines,
University of Utah.

PRACTICAL SUGGESTIONS FOR THE CONSTRUCTION OF CONCRETE FLOORS:
Engineering Experiment Station,
Pennsylvania State College.

TESTS OF CONCRETE AND REINFORCED CONCRETE COLUMNS:
Engineering Experiment Station,
University of Illinois.

TESTS OF REINFORCED CONCRETE BUILDINGS UNDER LOAD:
Engineering Experiment Station,
University of Illinois.

TESTS OF CEMENT:
Engineering Experiment Station,
Iowa State College.

THE DETERMINATION OF INTERNAL TEMPERATURE RANGE IN CONCRETE ARCH BRIDGES:
Engineering Experiment Station,
Iowa State College.

CONCRETE CONSTRUCTION FOR RURAL DISTRICTS:
Engineering Experiment Station,
Pennsylvania State College.

REINFORCED CONCRETE WALL FOOTINGS AND COLUMN FOOTINGS:
Engineering Experiment Station,
University of Illinois.

TESTS ON BOND BETWEEN CONCRETE AND STEEL IN REINFORCED CONCRETE BEAMS:
Engineering School,
University of Wisconsin.

TESTS ON THE PERMEABILITY OF CONCRETE:
Engineering School,
University of Wisconsin.

ELECTRICAL ENGINEERING.

RESULTS OF EXPERIMENTS ON THE EFFECT OF THE FORM OF ALTERNATING CURRENT WAVES UPON INCANDESCENT LAMPS:
Engineering Experiment Station,
Pennsylvania State College.

STREET LIGHTING: Engineering Experiment Station,
University of Illinois.

INDUCTANCE OF COILS: Engineering Experiment Station,
University of Illinois.

STARTING CURRENTS OF TRANSFORMERS, WITH SPECIAL REFERENCE TO TRANSFORMERS WITH SILICON STEEL CORES:
Engineering Experiment Station,
University of Illinois.

CHARACTERISTICS AND LIMITATIONS OF SERIES TRANSFORMERS:
Engineering Experiment Station,
University of Illinois.

ECONOMICS OF RURAL DISTRIBUTION OF ELECTRIC POWER:
Engineering Experiment Station,
University of Missouri.

INCANDESCENT LAMP TESTING:
Engineering Experiment Station,
Iowa State College.

COMPARATIVE TESTS OF CARBON, METALLIZED CARBON, AND TANTALUM FILAMENT LAMPS: Engineering Experiment Station,
University of Illinois.

LIGHTING COUNTRY HOMES BY PRIVATE ELECTRIC PLANTS:
Engineering Experiment Station,
University of Illinois.

ELECTRIC POWER ON THE FARM:
Engineering Experiment Station,
Iowa State College.

MECHANICAL STRESSES IN TRANSMISSION LINES:
Engineering Experiment Station,
University of Illinois.

INVESTIGATIONS OF RAILWAY TRAIN LIGHTING:
Engineering School,
University of Wisconsin.

THE ADVISABILITY OF ELECTRIFICATION OF THE ARKANSAS JUNCTION-BASALT DIVISION OF THE COLORADO MIDLAND RAILROAD:
Engineering School,
Colorado College.

FUELS.

A STUDY OF THE SPECIFICATIONS FOR THE PURCHASE OF COAL:
Engineering Experiment Station,
Pennsylvania State College.

STORAGE OF COAL: Engineering Experiment Station,
University of Missouri.

THE HEATING VALUE AND PROXIMATE ANALYSIS OF MISSOURI COALS:
Engineering Experiment Station,
University of Illinois.

FUELS—*continued.*

UNIT COAL AND THE COMPOSITION OF ASH:
Engineering Experiment Station,
University of Illinois.

THE WEATHERING OF COAL: Engineering Experiment Station,
University of Illinois.

TESTS OF WASHED GRADES OF ILLINOIS COAL:
Engineering Experiment Station,
University of Illinois.

THE SPONTANEOUS COMBUSTION OF COAL:
Engineering Experiment Station,
University of Illinois.

BAGASSE DRYING: Engineering School,
Louisiana State University and
Audubon Sugar School.

FUEL TESTS WITH HOUSE HEATING BOILERS:
Engineering Experiment Station,
University of Illinois.

FUEL TESTS WITH ILLINOIS COALS:
Engineering Experiment Station,
University of Illinois.

THE OCCLUDED GASES IN COAL:
Engineering Experiment Station,
University of Illinois.

THE COKING OF COAL AT LOW TEMPERATURES WITH A PRELIMINARY STUDY OF THE BY-PRODUCTS: Engineering Experiment Station,
University of Illinois.

HYDRAULICS.

MEASUREMENTS OF FLOWING STREAMS:
Engineering Experiment Station,
School of Mines,
University of Utah.

DREDGING BY THE HYDRAULIC METHOD:
Engineering Experiment Station,
Iowa State College.

THE ASSESSMENT OF DRAINAGE DISTRICTS:
Engineering Experiment Station,
Iowa State College.

A TOPOGRAPHICAL SURVEY OF THE SPIRIT AND OKONOGI LAKES REGION:
Engineering Experiment Station,
Iowa State College.

THE FLOW OF STREAMS AND THE FACTORS WHICH MODIFY IT, WITH SPECIAL REFERENCE TO WISCONSIN CONDITIONS:
Engineering School,
University of Wisconsin.

INVESTIGATION OF CENTRIFUGAL PUMPS:
Engineering School,
University of Wisconsin.

ROADS AND PAVEMENTS.

TRAP ROCKS OF THE PALOUSE REGION AS ROAD MATERIALS. (Two bulletins.)
Bulletin of the Agricultural Station,
University of Idaho.

TESTS OF MACADAM ROCK: Engineering Experiment Station,
School of Mines, University of Utah.

THE CONSTRUCTION AND MAINTENANCE OF EARTH ROADS:
Engineering Experiment Station,
School of Mines, University of Utah.

DRAINAGE OF EARTH ROADS: Engineering Experiment Station,
University of Illinois.

TESTS OF CAST-IRON AND REINFORCED-CONCRETE CULVERT PIPES:
Engineering Experiment Station,
University of Illinois.

VOIDS, SETTLEMENT, AND WEIGHT OF CRUSHED STONE:
Engineering Experiment Station,
University of Illinois.

AN INVESTIGATION OF THE ROAD-MAKING PROPERTIES OF MISSOURI STONE AND GRAVEL: Engineering Experiment Station,
University of Missouri.

HISTORY OF ROAD LEGISLATION IN IOWA:
Engineering Experiment Station,
Iowa State College.

SOME OBSERVATIONS OF THE QUALITIES OF PAVING BRICK:
Engineering School,
Ohio State University.

THE ROAD-BUILDING MATERIALS OF COSCHOCTON COUNTY:
Engineering School,
Ohio State University.

SANITATION.

DATA OF IOWA SEWAGE AND SEWAGE DISPOSAL:
Engineering Experiment Station,
Iowa State College,

SEWAGE DISPOSAL IN IOWA: Engineering Experiment Station,
Iowa State College.

THE PRODUCTION OF EXCESSIVE HYDROGEN SULFID IN SEWAGE DISPOSAL PLANTS AND CONSEQUENT DISINTEGRATION OF CONCRETE:
Engineering Experiment Station,
Iowa State College.

ELECTROLYTIC DISPOSITION OF SEWAGE:
Engineering School,
Ohio State University.

SANITATION AND SEWAGE DISPOSAL FOR COUNTRY HOMES:
Engineering Experiment Station,
University of Missouri.

SEWAGE PURIFICATION WITH SPECIAL REFERENCE TO WISCONSIN CONDITIONS: Engineering School,
University of Wisconsin.

STEAM AND BOILER PERFORMANCE.

LONG-DISTANCE TRANSMISSION OF STEAM AND ITS EFFECT UPON POWER-PLANT ECONOMICS: Engineering School, University of Wisconsin.

STEAM PIPE COVERING TESTS: Engineering Experiment Station, Iowa State College.

EXPERIMENTS WITH OIL BURNING IN BOILER FURNACES: Engineering School, University of Louisiana.

AN EXPERIMENTAL STUDY OF BAGASSE AND BAGASSE FURNACES: Engineering School, University of Louisiana.

FIRING TESTS OF MISSOURI COALS: Engineering Experiment Station, University of Missouri.

A REPORT OF STEAM BOILER TRIALS UNDER OPERATING CONDITIONS: Engineering Experiment Station, University of Missouri.

SUPERHEATED STEAM: Engineering School, Ohio State University.

HIGH STEAM PRESSURE IN LOCOMOTIVE SERVICE: Engineering Experiment Station, University of Illinois.

SUPERHEATED STEAM IN LOCOMOTIVE SERVICE: Engineering Experiment Station, University of Illinois.

THE STEAM CONSUMPTION OF LOCOMOTIVE ENGINES FROM THE INDICATOR DIAGRAMS: Engineering Experiment Station, University of Illinois.

THE EFFECT OF SCALE ON THE TRANSMISSION OF HEAT THROUGH LOCOMOTIVE BOILER TUBES: Engineering Experiment Station, University of Illinois.

TESTS OF TWO TYPES OF TILE-ROOF FURNACES UNDER A WATER-TUBE BOILER: Engineering Experiment Station, University of Illinois.

STRENGTH OF MATERIALS.

THE RESISTANCE OF TUBES TO COLLAPSE: Engineering Experiment Station, University of Illinois.

THE STRENGTH OF CHAIN LINKS: Engineering Experiment Station, University of Illinois.

TESTS OF NICKEL-STEEL RIVETED JOINTS: Engineering Experiment Station, University of Illinois.

AN INVESTIGATION OF THE STRENGTH OF ROLLED ZINC: Engineering Experiment Station, University of Illinois.

THE STRENGTH OF ALLOYS OF NICKEL AND COPPER WITH ELECTROLYTIC IRON: Engineering School, University of Wisconsin.

STRUCTURAL WORK.

A STUDY OF ROOF TRUSSES: Engineering Experiment Station,
University of Illinois.

TESTS OF BRICK COLUMNS AND TERRA COTTA BLOCK COLUMNS:
Engineering Experiment Station,
University of Illinois.

A STUDY OF BASE AND BEARING PLATES FOR COLUMNS AND BEAMS:
Engineering Experiment Station,
University of Illinois.

TESTS OF TIMBER BEAMS: Engineering Experiment Station,
University of Illinois.

AN INVESTIGATION OF BUILT-UP COLUMNS UNDER LOAD:
Engineering Experiment Station,
University of Illinois.

TESTS OF COLUMNS: Engineering Experiment Station,
University of Illinois.

STRENGTH OF I-BEAMS IN FLEXURE:
Engineering Experiment Station,
University of Illinois.

STRESSES AND TALL BUILDINGS:
Engineering School,
Ohio State University.

STRENGTH OF SEASONED TIMBER:
Engineering School,
University of California.

WATER SUPPLY.

WATER SUPPLY FOR COUNTRY HOMES:
Engineering Experiment Station,
University of Missouri.

ARTESIAN WATERS OF MISSOURI:
Engineering Experiment Station,
University of Missouri.

THE THEORY OF LOADS ON PIPES IN DITCHES, AND TESTS OF CEMENT AND CLAY DRAIN TILE AND SEWER PIPE:
Engineering Experiment Station,
Iowa State College.

THE SOURCES OF WATER SUPPLY IN WISCONSIN:
Engineering School,
University of Wisconsin.

MISCELLANEOUS.

THE PROGRESS OF THE CERAMIC INDUSTRY:
Engineering School,
University of Wisconsin.

A STUDY OF IOWA POPULATION AS RELATED TO INDUSTRIAL CONDITIONS:
Experiment Station,
Iowa State University.

TESTS OF SAND-BLASTING MACHINES:
Engineering School,
Ohio State University.

TESTS OF A LIQUID AIR PLANT:
Engineering Experiment Station,
University of Illinois.

MISCELLANEOUS—*continued.*

ON THE RATE OF FORMATION OF CARBON MONOXIDE IN GAS PRODUCERS:
Engineering Experiment Station,
University of Illinois.

FREIGHT-TRAIN RESISTANCE: Engineering Experiment Station,
University of Illinois.

HIGH-SPEED TOOL STEELS: Engineering Experiment Station,
University of Illinois.

PRELIMINARY TESTS ON SUGAR-HOUSE MACHINERY:
Engineering School,
University of Louisiana.

THE THERMAL CONDUCTIVITY OF FIRE CLAY AT HIGH TEMPERATURES:
Engineering Experiment Station,
University of Illinois.

A STUDY IN HEAT TRANSMISSION:
Engineering Experiment Station,
University of Illinois.

THE PROPERTIES OF SATURATED AND SUPERHEATED AMMONIA VAPOR:
Engineering Experiment Station,
University of Illinois.

DESIGN OF BLOWER HEATING SYSTEMS FOR SHOP BUILDINGS:
Engineering Experiment Station,
Pennsylvania State College.

III. THE ORGANIZATION OF THE ENGINEERING EXPERIMENT STATION AT THE UNIVERSITY OF KANSAS.

Believing that the organization of an engineering experiment station is an advantage to an engineering school in many ways, and that it is conducive to the best results in carrying on special investigations, the University of Kansas organized such a station in 1908, with the Dean of the School of Engineering as Director and the balance of the staff made up of the Chancellor of the University and the heads of the various engineering departments. The personnel of the present staff is given in the first part of this bulletin. Up to the present time the financial support of the University of Kansas Engineering Experiment Station has been through the appropriations granted to the various departments of the Engineering School, and the work of investigations has been carried on by men regularly appointed to the instructional staff, but relieved of teaching duties to some extent in order to give time for special investigations.

IV. BULLETINS WHICH HAVE BEEN ISSUED BY THE UNIVERSITY OF KANSAS ENGINEERING EXPERIMENT STATION.

The publication of bulletins is provided for through the regular University channels for issuing publications. Up to the present time the following bulletins have been published:

BULLETIN NO. 1. NOVEMBER, 1909.

A Ballistic Electrodynamometer Method of Measuring Hysteresis Loss in Iron..............*Martin E. Rice* and *Burton McCollum.*

Voltage Regulation of Alternators................*Burton McCollum.*

BULLETIN NO. 2. JULY, 1912.

Natural Gas: Its Properties, Its Domestic Use, and Its Measurement by Meters.................................*P. F. Walker.*

BULLETIN NO. 3. JANUARY, 1913.

Kansas Fuels: Coal, Oil, and Gas. Heating Values and Proximate Analysis of Coal......*P. F. Walker* and *Walter Bohnstengel.*

Discussion of Sulphur Content of Bituminous Coal. *Walter Bohnstengel.*

BULLETIN NO. 4, PART 2. OCTOBER, 1913.

Vocational Education in Kansas, with Courses of Study Now Offered by the University School of Engineering.

"*A Ballistic Electrodynamometer Method of Measuring Hysteresis Loss in Iron,*" by Martin E. Rice and Burton McCollum.

This article is a description of an accurate and at the same time thoroughly practical method of determining the hysteresis loss in samples of commercial sheet iron or steel such as is used in electrical manufacturing for the cores of armatures and transformers. The method is the outcome of special investigations carried out by the authors, and the results to be obtained by its use are of the same order of accuracy as those obtained by the very tedious ballistic galvanometer method. The rapidity with which tests can be made by this new method is equal to or greater than that of less accurate methods which have been employed commercially.

"*Voltage Regulation of Alternators,*" by Burton McCollum.

This, the second article in Bulletin No. 1, outlines the methods in general use in predetermining, without loading, the voltage regulation of alternating-current generators. The errors inherent in these methods are discussed, after which the author describes a method of determining the synchronous impedance of the armature of an alternator for different positions of the armature with respect to the field, and a method of using these values in the predetermination of the alternator regulation. The experimental work shows that the regulation, as predetermined by this method, is nearer the true regulation than the values obtained by the methods ordinarily employed.

Bulletin No. 1 should prove of use to manufacturers and users of electrical machinery.

"*Natural Gas: Its Properties, Its Domestic Use, and Its Measurement by Meters,*" by P. F. Walker.

This bulletin, No. 2, describes the results of the investigations undertaken by Professor Walker at the request of the Public Utilities Commission of Kansas and covers the matters of the composition of natural gas, the law of gases, the heat value of natural gas, its efficient use for

cooking and heating, and the construction and accuracy of the ordinary gas meter as used on the consumer's premises. The material in this bulletin is of interest to citizens in the localities in Kansas, Missouri, and Oklahoma where natural gas is used for domestic consumption.

"*Kansas Fuels: Coal, Oil, and Gas. Heating Values and Proximate Analysis of Coal*," by P. F. Walker and Walter Bohnstengel.

This report covers the results of very extensive investigations of the fuels found in the state of Kansas. Numerous samples from the various coal beds and the oil and gas fields were collected, analyzed, and tested for heating values. The work was carried out by the Department of Mechanical Engineering working in conjunction with the Chemical Engineering Department and the State Geological Survey.

"*Discussion of Sulphur Content of Bituminous Coal*," by Walter Bohnstengel.

This discussion results from the work done by Mr. Bohnstengel, first at the University of Kansas, and later coöperating with the University as engineer of tests with the Atchison, Topeka & Santa Fe Railway System at Topeka, Kansas.

Bulletin No. 3 contains information of use to all industries which use Kansas fuels for heating or power purposes.

"*Vocational Education in Kansas, with Courses of Study now Offered by the University School of Engineering.*"

The matter of vocational education is of such great importance at the present time that it was thought advisable for the Engineering Experiment Station to give it some attention, and the first results have been to issue a part of a bulletin outlining what has been done along this line at the University of Kansas. This publication is for distribution among those interested in this particular line of education.

V. WORK IN HAND UPON WHICH CONSIDERABLE INVESTIGATION HAS ALREADY BEEN DONE AND ON WHICH BULLETINS WILL BE ISSUED IN THE NEAR FUTURE.

A complete survey of the water supply for Kansas towns and cities has been made and the results of this work will be published in an early bulletin. For several years the engineers of the State Board of Health have been members of the Faculty of the Civil Engineering Department of the University of Kansas and all plans for water supplies and sewer systems of the cities of the state have been subject to their approval. The Department of Chemistry handles all of the water analyses, and the survey is the result of the investigations of these two departments, acting in conjunction with the State Geological Survey, an independent organization of the University. This survey is prepared primarily for the use of the municipalities of the state of Kansas.

Integrating electrical meters for the measurement of electrical energy supplied to the consumer and the effects of voltage regulation upon the performance of incandescent lamps are two electrical subjects which have received some attention

by the Station, and a bulletin covering these subjects will be published at a later date. This publication will describe the construction and operation of modern electrical supply meters and discuss their reliability, probable error, inspection, care, and tests. The importance of good voltage regulation on the supply lines, where incandescent lamps are used, and the matter of selecting a lamp of the proper voltage rating when the line potential is known, will be carefully treated. The material for this bulletin will be derived from the results of very extensive tests made in various sections of the country and by various organizations, together with the work carried out in the electrical laboratories at the University of Kansas. It is planned to prepare this bulletin for the use of managers of the small and moderate-sized electric lighting systems which now are so numerous in Kansas.

The newly organized Department of Architectural Engineering, under the direction of Professor Goldwin Goldsmith, will prepare a set of house plans for a modern residence with a view to aiding in the establishment of a high standard of architecture in the building of homes in Kansas. This department, acting through the Engineering Experiment Station, plans to help in the maintenance of a standard of good architecture and building construction for both public and private buildings throughout the state.

The results of experiments in the washing of Kansas coals are about ready for publication. A considerable amount of work has been done by the Department of Mining looking toward the publication of specific economic results to be obtained through the washing of certain of the Kansas coals before using them for the generation of steam. The results of these experiments will be distributed to mine owners and to the industries using Kansas coals.

The flow of water in Kansas streams and the relation of rainfall to run-off in different basins of the state. A start has been made toward collecting extensive data on this important subject and the investigations will be continued until the results are sufficiently complete to warrant their publication.

VI. SHORT TITLES OF SUBJECTS UPON WHICH INVESTIGATIONS MAY BE UNDERTAKEN OR CONTINUED.

CIVIL ENGINEERING.

The Adaptability of Kansas Rock to Road Building.

A Study and Classification of the Different Commercial Bituminous Paving Materials.

Methods of Waterproofing Cement Mortars and Concrete.

General Survey of Concrete Aggregate, Sand and Stone, of the State.

Investigation as to Time of Removal of Forms from Concrete.

The Effect of Temperature on the Time of Setting of Concrete.

An Investigation of the Highway Bridges of the State and Improvements in Design.

The Effect of Repeated Stresses on Concrete.

Investigation of Stresses in Railroad Track.

Study of Railroad Track Drainage.

Investigation of Paving Brick of Kansas.

SANITARY ENGINEERING.

Results of Analyses of the Natural Waters of Kansas.

Investigation of Methods of Sewage Disposal Suited to Conditions in Kansas.

The Relation of Water Supplies, Water Purification, Sewerage, and Sewage Disposal to the Public Health of Kansas Cities.

The Relation of Air Supplies to Public Health Problems.

The Purification of Water Used in Swimming Pools.

An Investigation of the Suitability of the Sands of Kansas as Filter Media in Water Purification.

ELECTRICAL ENGINEERING.

The Supply of Electricity for Lighting and Power in Small Cities.

The Fixing of Fair Rates for Electricity When Furnished by Small Plants.

Data Covering "White Way" Lighting Systems as Such Systems are Adapted to Kansas Cities.

An Investigation of the Starting of Synchronous Motors and the Operating Characteristics of Such Motors.

MECHANICAL ENGINEERING.

Investigation of Losses in Automobile Transmission Gears.

The Burning of Low-grade Fuel in Boiler Furnaces.

Effects of Moisture Injected Into the Cylinders of Gasoline Engines.

The properties of Lubricating Oils.

MINING ENGINEERING.

Relation of Mine Laws and Law Enforcement to the Coal Mining Industry.

Survey of Kansas Coals with Regard to Improvement by Washing.

Efficient Concentration of Lead-Zinc Ores.

ARCHITECTURAL ENGINEERING.

School Buildings, Grade and High Schools, with Particular Reference to Fireproofing, Lighting, Ventilation, and Sanitation.

Fair Buildings of Various Kinds.

Courthouses and Other County and Municipal Buildings.

The Preparation of Standard Building Laws Suitable for Communities of Different Sizes.

VII. Description of the Equipment Immediately Available for the Use of the Engineering Experiment Station.

The work of the Engineering Experiment Station is carried out mainly in the laboratories of the engineering schools, and the equipment provided for the use of these laboratories is available for the experimental work of the state. A good library is an essential part of the equipment of any experiment station, and the general University library as well as the li-

ENGINEERING LIBRARY.

braries of the departments of Architectural Engineering, Chemistry, Civil Engineering, Electrical Engineering, Geology and Mining, and Mechanical Engineering are open for the use of investigators. Every effort is made to keep the department libraries as complete as possible and to have on file the very latest publications along the various special lines of engineering.

The following descriptions of the engineering laboratories are taken from the University catalogue.

CIVIL AND SANITARY ENGINEERING.

The instruments for field work in civil engineering comprise transits, levels, compasses, solar attachments, rods, chains, tapes, plane tables, heliotropes, current meters, aneroids, and other minor instruments. Among these are a precise level for very accurate leveling, a secondary triangulation transit for topographical work, and an altazimuth instrument for use on primary triangulations, which has a ten-inch circle, read to single seconds of arc.

For the summer work in surveying a complete camping outfit is provided. Planimeters, Thatcher and Manheim slide rules, and Colby's stadia slide rules are used for rapid calculation and estimation of quantities.

The cement laboratory affords facilities for extended investigation work as well as for the current undergraduate courses.

The road-materials laboratory contains various machines for testing the strength, resistance to abrasion, and the cementing power of the dust of stone, the value of which as material for the building of rock roads is under investigation.

The sanitary laboratory is equipped with apparatus for the investigation of water and sewage. It is not designed to supplant the chemical laboratories, but to afford means for making approximate and quick

CEMENT LABORATORY.

analyses for engineering purposes of samples suspected of contamination. The laboratory is also to be used in connection with research work along sanitary lines, in connection with an experimental plant for the treatment of the sewage from some of the University buildings.

MECHANICS.

The testing-of-materials laboratory, situated in the basement of Marvin Hall, is equipped for making tests on all kinds of structural materials.

The principal machines are a 200,000-pound Olsen universal testing machine capable of testing beams up to twenty feet in length and columns up to ten feet in height; two 100,000-pound and one 40,000-pound universal testing machines; a 50,000-inch-pound Olsen torsion machine; a White-Souther alternate-stress machine, and a standard rattler for testing paving brick. The laboratory is well equipped with small apparatus, such as extensometers, both direct-reading and autographic, compressometers, etc.

The concrete laboratory is provided with mixing machinery, molds for making test pieces, and apparatus for the mechanical analysis of sands and cements.

The hydraulic laboratory contains a measuring pit, a large steel orifice tank for experimentation with jets, a triplex power pump, two centrifugal pumps, pipe lines, weir boxes, gauges, a Venturi meter with manometer, a Pelton water motor, etc., arranged to illustrate the laws of fluid motion, and affording some opportunity for testing hydraulic machinery.

TESTING MATERIALS LABORATORY.

ELECTRICAL ENGINEERING.

The electrical engineering laboratories are situated in Marvin Hall and comprise a dynamo laboratory, a standardizing laboratory, a photometer room, and space for the telephone equipment.

The dynamo laboratory is fitted with a complete line of both alternating- and direct-current machines, the former varying in capacity from a two-horsepower motor to a 50-kilowatt generator, while the direct-current machines range in capacity from one and one-half kilowatts to 20 kilowatts. These machines have been selected especially with a view of supplying a complete set of experimental machines and to illustrate modern design and practice in dynamo-electric machinery. Individual motor drive is used for all experimental work, and a chain hoist and trolley have been provided for use in quickly moving any of the machines to the position in which they may be required. Very few permanent connections are used, but the switchboards, connecting boards, and testing tables have all been especially designed to facilitate the connection of any piece of apparatus to a proper power supply. Direct current is supplied from the University power plant, but all other voltage supply is through the agency of motor-generator sets in the laboratory. The machines in this room are used also as sources of current supply for the other electrical laboratories. The assortment of field and load rheostats, transformers, reactance coils, etc., is adequate.

In the standardizing laboratory provision is made for the calibration of all types of electrical measuring instruments and for the study of problems in electrical measurements. The equipment consists of a potentiometer, an A. C. - D. C. comparator; laboratory standard ammeters, voltmeters, and wattmeters; a precise Wheatstone bridge; a portable testing set; an inductance bridge; and a three-element oscillo-

graph. These instruments are all equipped with a complete set of auxiliaries such that any ordinary range of potential or current in either direct or alternating currents may be measured. A storage battery is provided as a source of steady current for use in calibrating instruments. The portable instruments used in the dynamo laboratory are cared for in the standardizing room. This set of instruments is very complete and includes the best of foreign as well as American manufacture. In addition to the instruments in regular use this set contains portable meters of suitable types and ranges for the tests of power plants or of machines in regular commercial operation.

The photometer room is fitted with a 300-centimeter photometer bar, which is provided with necessary lamp holders and auxiliaries for the testing of the different types of lamps used in artificial illumination. A Bunsen screen, a Lummer-Brodum screen, and a flicked photometer have been provided for use in connection with this bar. A portable photometer of the Sharp-Miller type is used for studying the illumination of streets and buildings.

ELECTRICAL LABORATORY.

The telephone laboratory has an assortment of modern telephone apparatus. This includes complete sets for illustrating installations, of both local battery and central energy types. The best selective systems are represented, as well as a complete small automatic telephone system.

MECHANICAL ENGINEERING.

The mechanical laboratory is a room 48 by 100 feet, with a gallery 16 feet wide extending across one end and along one side about 60 feet. On the gallery floor are office, computing room, storeroom, instrument room, oil room fitted up with special apparatus for testing lubricants, and a fuel-testing room equipped with a Mahler bomb calorimeter, a Parr calorimeter, and apparatus for coal and gas analysis.

On the main floor are installed a 100-horsepower experimental boiler of Stirling water-tube type; an independently fired Foster superheater; a 10 by 24 by 30-inch cross-compound Monarch Corliss steam engine, arranged to belt to a 55-kw. direct-current generator; a 75-horsepower Ball automatic high-speed engine; a 20-horsepower De Laval steam turbine coupled to a centrifugal pump used for circulating water for the condenser; a 10-horsepower Atlas slide-valve engine; a C. H. Wheeler surface condenser of 600 square feet surface, equipped with wet and dry vacuum pumps; a 100-horsepower two-cylinder tandem Riverside gas engine direct-connected to the 55-kw. generator above mentioned; two 8-horsepower gas or gasoline engines; a 75-horsepower Smith suction gas

producer; a five-ton Cleveland ammonia compressor, motor driven, with submerged condenser and fittings complete, including a small ice box (can system), and an auxiliary brine cooler; several lubricant-testing machines; a complete air-brake outfit for train service; and other minor pieces of apparatus. A representative outfit of engine indicators, steam calorimeters, etc., is owned by the department.

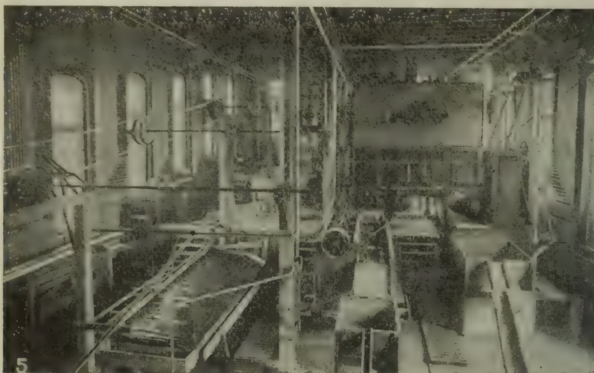
MECHANICAL ENGINEERING LABORATORY.

PRIVATE OFFICE OF THE DEAN OF THE SCHOOL OF ENGINEERING.

MINING ENGINEERING.

The building for geology and mining (Haworth Hall) was so planned as to give excellent opportunity for the concentration of ores. The ore-dressing laboratory, 40 by 80 feet, is connected to the main building by a corridor, and is so placed on a slope that the floor is divided into four steps, allowing ore to be carried from one floor to the other by gravity.

The equipment consists of crushing, screening, and classifying apparatus of various kinds, giving practice in all of the principal processes of ore dressing. There has recently been added a coal-washing plant for experimental work on a large scale. The mining museum contains models of mines and a collection of mills and apparatus used in mining and milling operations. A large laboratory has been equipped for making a thorough and complete examination of the clays of Kansas.



MINING LABORATORY.

CHEMICAL ENGINEERING.

The chemical laboratories are located in the Chemistry and Pharmacy Building. They contain separate rooms for general chemistry, qualitative analysis, quantitative analysis, organic chemistry, physical chemistry, water analysis, food analysis, assaying, and metallurgy. Dispensing and balance rooms and the offices of the instructors are conveniently located about the building. There are several lecture and recitation rooms, the largest seating more than three hundred students. There is also a departmental library, containing sets of the principal chemical journals, as well as carefully selected reference books upon the subject. The department is well supplied with all the necessary and usual apparatus for lecture illustration and demonstration, for laboratory work in all the undergraduate courses, together with adequate equipment for effective graduate and research work in analytical, organic, physical, industrial, and metallurgical chemistry. A somewhat unusual piece of equipment is a well-working liquid-air plant, which affords excellent opportunity for work at low temperatures.

THE FOWLER SHOPS.

The equipment of the shops is selected with a view to its being the means of teaching modern methods of machine construction, rather than to develop individual skill. The order of progress of the student through the various departments is consistent with the same idea.

In producing castings for machines the first step of pattern making is provided for, in a room 50 by 80 feet on the second floor, by benches and bench tools of high class, sufficient for a class of eighteen in a single section; twelve Richardson 11 by 28-inch speed-lathes with full tool equipment; a complete pattern-maker's lathe, 18 inches by 12 feet, and a 7-foot faceplate lathe; a combination table saw, an Oliver band saw, and a scroll saw; a power-driven boring machine and a sandpapering machine, motor-driven group system; and special hand tools to facilitate accurate and rapid work. The second step—that of the actual casting—is provided

for by foundry equipment in a room 60 by 66 feet, consisting of a Whiting melting cupola of one and one-half tons capacity per hour; a brass furnace complete; an automatic molding machine; a core machine and full equipment for core work; and all necessary hand tools for work in a molding room, arranged in typical modern fashion. An elevator to the cupola-charging platform, and a geared tumbler and a grinder for cleaning castings, are included.

For preparing wrought metals, and for making cutting tools, the forge shop, 40 by 50 feet, is equipped with sixteen Sturtevant down-draft forges and one large forge for heavy work, with a full complement of smithing tools, a Little Giant power hammer to facilitate rapid work and to familiarize students with its use.

For the final work of machine construction, the machine shop, a room 50 by 80 feet, is supplied with fourteen 14 in. by 6 ft. Standard engine lathes; one 18 in. by 12 ft. and one 14 in. by 5 ft. Challenge engine lathes with full attachments; one Jones and Lawson 2 in. by 24 in. turret lathe with chucking attachments; one 26 in. by 26 in. by 7 ft. Gray planer; one Universal milling machine with spiral gear cutter and all attachments; a Lucas No. 21 precision horizontal boring, drilling and milling machine, with individual motor; one 15 in. crank shaper; one 25 in. Challenge drill press with automatic feed; three 20 in. drill presses; one sensitive drill press; one 1½ in. bolt cutter; one Universal cutter and reamer grinder; one Yankee drill grinder; and other power dry and wet grinders, etc. The room has 160 feet of benches with twenty vises and a good outfit of hand tools, which, with stock and supplies, are kept in a tool room under the care of a skilled attendant, the students being held to a rigid observance of shop rules. Electric-motor drive by the group system is used throughout the shop.

THE POWER PLANT.

The power plant is in the same building with the mechanical engineering laboratory, and is designed for the double purpose of furnishing light and power to the entire University and of giving engineering students an opportunity to study power costs with modern equipment.

The boiler-room equipment consists of two 150-horsepower Bonus-Kennicott water-tube boilers, equipped with Jones underfeed stokers; a Sturtevant economizer; and an induced-draft system with a motor-driven fan. A pressure of 150 pounds is carried. All feed water is metered with a Worthington piston meter, and coal-weighing scales are provided.

In the generator room is a 150-kw. 115-230 volt three-wire direct-current Western Electric generator, direct-connected to an 11 in. by 19 in. by 16 in. cross-compound Ball engine making 225 revolutions per minute; a 100-kw. 2300-volt, three-phase 60-cycle Curtis turbo-alternator built by the General Electric Company; a 75-kw. motor-generator set for alternating-current and direct-current, with synchronous motor, by means of which both forms of current may be delivered with one steam machine in operation; one 8 in. by 12 in. by 7 in. by 12 in. compound duplex Advance service pump for the general water supply of the University, and one large high-pressure Underwriter's pump for fire protection.

All the main engines and pumps exhaust into one 1200 sq. ft. surface condenser equipped with both wet and dry vacuum pumps for high-vacuum service and a centrifugal circulating pump. All pumps are motor driven. Crane pipe and fittings have been used throughout the plant.

The switchboard is of General Electric design, and is fully appointed, with complete outfit of recording and indicating meters. Six single-phase lighting circuits, one three-phase power circuit, and three three-wire direct-current power circuits supply the University buildings through an underground conduit system installed by the Standard Underground Cable Company.

VIII. COÖPERATION WITH ORGANIZATIONS WHOSE OBJECTS, AT LEAST IN PART, ARE OF THE SAME GENERAL NATURE AS THOSE OF THE STATION.

The Experiment Station is not limited in the carrying out of its investigations to the facilities within the Engineering School, but the equipment of the other schools of the University are at its disposal when such equipment is desired for special purposes. Likewise members of the faculties of the other schools are free to coöperate with the staff of the Engineering Experiment Station when the investigations, as undertaken, call for the services of experts in other lines than engineering. Where the facilities for carrying on some special work are better at the laboratories or plants of industrial organizations, these organizations have been very willing to coöperate with the Engineering School in the carrying out of the investigations of the Station which could be better done at these places. It is the desire of the Station staff to work in coöperation with the industries of the state, with the other engineering schools, and with all organizations which have for their object the general benefit of the citizens, the industries and the engineering profession of the country.

IX. THE INDUSTRIES OF THE STATE OF KANSAS.

Agriculture is the leading pursuit in the state of Kansas, with farm products totaling a value of nearly $500,000,000 per year. The state ranked fifth in the United States in value of farm lands ($203,938,910) according to the last census reports. Kansas has 8915 miles of railways, and the operation of these roads forms one of the large industries of the state. The manufacturing in the state is largely the outcome of its extensive agricultural resources, but the other natural resources of zinc and coal and of oil and gas have given an impetus to manufacturing, and the growth in this line of industry has been very marked in the last few years. The 1909 report of the Bureau of the Census credits the state with 3434 manufacturing establishments, giving employment to 54,649 persons, with expenditures of $305,711,000, and added wealth due to manufactured products of $66,220,000. In 1904 there were but 2475 establishments, producing an added wealth of $41,735,000. It is fair to believe that the rate of growth in the last five years has not been less than from 1904 to 1909.

The importance of manufacturing in the state is evidenced by the rapid growth within the last few years. The principal manufactured products, based upon their value as a percentage of the total value, are: Packing-house products (50.9%, 1909 census); flour and grist-mill products (21.1%); cars, general shop construction, and repairs by steam-railroad companies (3.4%); zinc smelting and refining (3.3%); printing and publishing (2.2%); butter, cheese, and condensed milk (1.9%); foundry and machine-shop products (1.8%); brick, cement (1.8%); lumber (1.0%); glass (0.6%); and tile (0.7%). While the value of cement and glass products does not form a very large percentage of the whole, these industries, in Kansas, ranked fourth among the states in the production of cement, and eighth in the value of glass products.

Enough has been said to show that the industries of the state, aside from agriculture, are of considerable and of growing importance, and one of the fields of the Kansas Engineering Experimental Station is to bring the facilities of the Engineering School to the direct aid and benefit of these industries.

THE UNIVERSITY OF KANSAS.

ENGINEERING EXPERIMENT STATION.

BULLETIN NO. 4. OCTOBER, 1913.

PART 2. VOCATIONAL EDUCATION IN KANSAS, WITH COURSES OF STUDY NOW OFFERED BY THE UNIVERSITY SCHOOL OF ENGINEERING.

By P. F. WAKER, Dean of School of Engineering.

CONTENTS.

VOCATIONAL EDUCATION IN KANSAS.

The distinctive feature of present-day industrial progress is the development of the individual workman. In addition to the tremendous advances which have been made in the past century along the lines of power application to manufacturing processes and improvement of all machinery types, it has come to be recognized that the efficiency of the worker himself is an element of increasing importance. The growth of this idea has brought about a change in the educational needs and in the methods employed in the training of those who are to engage as employees in the manufacturing industries.

THE ENGINEERING SCHOOL IDEA.

During the period when the emphasis was being placed upon power applications and improvement of specialized machinery, the training of a comparatively small number of master minds was essential. Expert designers and inventors could do the creative work and determine the progress which should be made in the art. The development of the high-grade technical schools has been the natural result of this need and constitutes the most significant advancement of the last century in matters relating to education in professional branches.

VOCATIONAL TRAINING NEEDED.

The need for the highly trained specialist continues, and the high-grade technical schools are filled and will continue to be filled with men who will find their work and their opportunities in the constructive work of the present and the future, but there is coming to be felt the need for a more adequate training of those who are to do the detailed work. Many of the large corporations of this country are providing for this need by establishing special training schools for their apprentices. They are doing this in order to provide for their own requirements, and the boy is fortunate, from the educational viewpoint, who is included in their ranks, unless he has sacrificed opportunities which he may have had to follow a higher and more complete course of training. As compared with the majority of his associates, he is fortunate in that he is being prepared in a systematic manner for the work of the trade by which he will make his living. Those boys who pass directly from the grade schools into the employment of the ordinary business firm have received no special training whatsoever. This is not said in criticism of the public-school system, since that system is directed toward results other than the specific vocational training of the young.

It has been recognized by various European countries, and in several states in this country, that vocational education is a matter coming properly within the scope of the public schools. This does not mean that the public schools should be made to include studies and work of a voca-

tional character, but that the public should make provision for those whose conditions in life make it necessary for them to enter directly upon gainful occupations at an early age. The resulting benefits accrue to the individuals themselves, and to the state at large, in far greater measure than to the specific industries. With governmental supervision and control becoming cardinal elements in the industrial system, the education of workers in specific lines at public expense assumes an importance equal to that of general education for good citizenship.

MANUAL TRAINING AND TRADE SCHOOLS INADEQUATE.

It should be understood at the start that vocational education does not of necessity mean the teaching of trades in the public schools or any branch of the public-school system. Manual training, as it is carried on in schools, is valuable from very many points of view and gives an opportunity for many to discover aptitudes for various lines of work, but neither it nor the instruction given in *bona fide* trade schools quite meets the need of the masses.

A very large proportion of the boys leave the grade schools before they have had opportunity to profit from the manual-training instruction, and but few can ever leave home to attend the established trade schools. It is out of the question for most of the cities and towns to attempt to build up complete trade schools in which an adequate preparation for actual work on a remunerative basis can be given. The various trades and callings into which young people can go are so numerous as to make such a method of meeting the needs impracticable. The remedy is not to be sought, therefore, in an extension of the manual-training idea, with the thought that children who are giving their whole time to attendance upon the schools can thereby learn the trades.

THE CONTINUATION SCHOOL.

A method which has proven to be most effective in reaching the children of all classes, and which is within the reach of every town with a moderate financial investment, is that of the Continuation School. In its truly successful form there is united with it a legal requirement compelling employers of children within certain ages to give freedom from work for a certain number of hours a week, during which time the child in turn is compelled to attend a special school which is provided. By a proper selection of hours the special session for these children may utilize existing school property, and in some cases the same instructors are employed, thus making the additional expense to the community but nominal in amount.

Under such conditions any community in which there are opportunities for the regular employment of children above the age of compulsory school attendance can provide for the continued training of those who are compelled by circumstances to enter gainful occupations, and these schools make possible the giving of specialized instruction fitted to the nature of the various occupations represented by the pupils. In a real sense, therefore, the public and the special industry giving employment to the child unite in giving the training required in order to make him

an efficient member of society. The one agency is continuing his education along lines which bear mutually upon the child's material progress and his value as a citizen, while the other is giving the specific instruction and training in the actual methods of carrying out the work in which he is engaged. This mutuality of interests is one of the basic principles on which the Continuation School is based.

GERMAN SYSTEM MODIFIED.

In Germany this method of dealing with the problem of the child who is to enter the industrial ranks has been developed in its most perfect form. The child whose future occupation may be forecast is taken at an early age from the regular schools, and is placed in other schools which give instruction of a more specific nature. With the school system in vogue in this country this first division would not be made and is not desirable. In the German system, however, at an age corresponding to the limiting age of compulsory school attendance, the child is expected to stop regular daily attendance and enter upon some form of work. They then enter the Continuation School for five or six hours each week where they continue the study of their native language, studies of life and citizenship, mathematics, mechanical drawing, elements of bookkeeping and accounting. In several of these subjects the emphasis may be so placed that the studies will have a direct bearing upon the actual daily work of the child. When this idea is worked out to suit conditions in the United States various minor specialties may be introduced, including, for the girls, various forms of domestic science, and for the boys in towns where manual training facilities are provided, practice work of a somewhat more varied nature than they may be securing in their occupations.

Since many boys will be engaged in employments which are but temporary in character, such as messenger service and many kinds of irregular job work, it is desirable that they should be given opportunities to find out the true tendencies of their natures by means of such manual work. In its broadest sense, this general plan of procedure is true vocational training with which should be carried on a carefully guarded plan for exercising vocational guidance, although in the true sense of the term it does not involve the actual teaching of trades.

CONDITIONS IN KANSAS.

In dealing with the conditions now existing in Kansas another element must be taken into account. Many young men above the ages of those who would be included in a plan like that which has been outlined above are employed in the manufacturing and milling industries of the state, and these men would be profited by special studies pertaining to their work. Even were the Continuation School plan carried out with good efficiency throughout the larger cities and towns, there would still exist this demand for opportunities to carry on studies of a technical or semi-technical nature allied to engineering. The higher educational institutions of the state, maintaining a teaching staff and equipment for technical work in engineering and closely associated lines, are in a posi-

tion to carry on this work to assist cities and towns in establishing the more general work of the Continuation School. The two classes of instruction are different in many essential respects, occupying different fields and dealing with persons of quite different ages and circumstances, but they are readily coördinated. Each is of great importance, however, and may exert a great influence upon the industrial conditions of the state.

One element which may be considered essential for the successful development of the manufacturing interests in a community or state is the presence of a population accustomed to factory conditions and reasonably efficient in varied lines of work peculiar to many manufacturing processes. The more highly developed this population is the stronger will be the industries drawing upon them. In a very real sense, therefore, the establishment and maintenance of the kinds of instruction here referred to will have a potent influence upon the future development of the state.

THE PLAN OF THE UNIVERSITY.

In the following pages there is outlined the method which has been adopted by the University through its Extension Division for carrying on the work of the second kind, mentioned above. It is the hope and expectation that there are many young men in various plants and shops throughout the state who will be inclined to make up the studies which are offered. The institution is ready also to coöperate wherever it is possible with cities where there is a desire to establish schools for evening study or for any of the special branches in which technical work is involved. By these methods the extensive equipment of the University School of Engineering, as well as its teaching staff, may become of added value to the state and made available to a large number of the young men who are able to profit by the work offered.

UNIVERSITY OF KANSAS.

School of Engineering.

ADMINISTRATIVE OFFICERS.

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University Extension: Engineering Branches.

The faculty of the School of Engineering is the legislative body which deals with all questions relating to the instruction given in the several branches of Vocational Education, related to engineering and the manufacturing industries. All questions pass to the Board of Administration for ratification.

The faculty includes all professors and associate professors who give instruction in the School of Engineering, and those assistant professors and instructors giving instruction who are especially assigned to this faculty. The list of members of the instructional staff on the following pages includes only those who are in direct charge of correspondence-study work under this School.

INSTRUCTIONAL STAFF.

DEWITT C. CROISSANT, Ph. D.
Director of University Extension Division.

CHARLES H. TALBOT, A. B.
Secretary of Correspondence-Study Department and head of Municipal Reference Bureau.

Engineering Branches.

P. F. WALKER, M. M. E.
Dean of the School of Engineering.
Professor of Mechanical Engineering.

ERAMUS HAWORTH, B. S., M. S., Ph. D.
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Professor of Railway Engineering and Surveying.

HERBERT A. RICE, C. E.
Professor of Mechanics and Structural Engineering.

GOLDWIN GOLDSMITH, Ph. B.
Professor of Architecture.

CLINTON M. YOUNG, B. S., E. M.
Associate Professor of Mining Engineering.

GEORGE J. HOOD, B. S.
Associate Professor of Mechanical Drawing.

FREDERICK H. SIBLEY, B. S., M. E.
Associate Professor of Mechanical Engineering.

W. H. TWENHOFEL, A. M.
Associate Professor of Geology.

CHARLES COCHRAN.
Assistant Professor of Mechanical Drawing.

ALFRED H. SLUSS, B. S. in M. E.
Assistant Professor of Mechanical Engineering.

CLARENCE A. JOHNSON, B. S.
Assistant Professor of Electrical Engineering.

JOHN D. GARVER, B. S.
Assistant Professor of Mechanical Engineering.

FRANK L. BROWN, B. S.
Assistant Professor of Mechanics.

SAMUEL MCMULLAN, A. B., A. M.
Instructor in Machine-shop Practice and Cost Accounting.
Organizer for Vocational Extension Work.

O. A. BEATH, A. B., A. M.
Instructor in Chemistry.

ANNOUNCEMENT OF COURSES.

GENERAL CLASSIFICATION.

The subjects offered by the School of Engineering of Correspondence-Study are grouped under two general headings, as follows:

First, certain studies which are essentially the same as those offered to regular students in engineering. Before enrolling in them, a student must have done the equivalent of a considerable portion of the usual high school work, which training may be acquired by doing the work called for in some of the studies in the second general group, as described in the following pages, or by taking studies which are offered by other departments under the University Extension Division and there designated as high school work. In case a student wishes to secure full credit in the School of Engineering for any of these studies, he must have secured all of the credits necessary for entrance to the School. A statement of these requirements will be found at the end of this bulletin.

Second, vocational studies. Any one who has passed through the usual work of the grade schools up to the sixth grade and who is 15 years of age or older may enroll in these studies in their proper order, but no credit can be given for any of them counting for a degree in the School of Engineering. Only two may be taken at one time, but as soon as one is completed the student may take up the next subject in order without delay or extra expense. For statement of fees and expenses see page 19.

LIST OF STUDIES OFFERED.

NOTE.—Under the first general heading each subject is called a "course" and designated by number. This is in accordance with the practice followed in regular university work. In descriptions of the vocational work the word "course" is used exclusively to mean a full group of subjects as laid out to give systematic training for any designated line of work.

FIRST GROUP: COURSES OF UNIVERSITY GRADE.

Course 1. Free-hand and Mechanical Drawing.
24 assignments, 2 hours Engineering credit.

Course 2. Machine Drawing.
24 assignments, 2 hours Engineering credit.

Course 3. Elementary Mechanics.
16 assignments.

Course 4. Mechanism and Machine Design.
32 assignments, 3 hours Engineering credit in Electrical Engineering course.

Course 5. Highway Engineering.
16 assignments.

Course 6. Power Plant Engineering.
40 assignments, 3 hours Engineering credit in Civil or Electrical Engineering course.

Course 7. Direct Current Electrical Engineering.
32 assignments.

Course 8. Alternating Current Electrical Engineering.
32 assignments.

Course 9. Principles of Illuminating Engineering.
24 assignments.

Course 10. Mine Surveying or Mine Engineering.
40 assignments.

Course 11. General Mining.
40 assignments.

Course 12. Coal Mining.
40 assignments, 5 hours Engineering credit.

Course 13. Ore Dressing: Concentration of Ores.
40 assignments.

Course 14. Elementary Mineralogy.
40 assignments, 5 hours Engineering credit.

Course 15. General Geology.
40 assignments, 5 hours Engineering credit.

Course 16. Economic Geology.
40 assignments, 5 hours Engineering credit.

Course 17. Elements of Telephony.
24 assignments.

Course 18. Reinforced Concrete. Elementary course.
24 assignments.

Course 19. Reinforced Concrete. Advanced course for Graduate Engineers or Advanced Students.
24 assignments. 3 hours Engneering credit.

Course 20. Architectural Drawing.
Part 1, 20 assignments.
Part 2, 20 assignments.
3 hours Engineering credit if 5 assignments are done in residence.

Course 21. Architectural Design.
Part 1, 20 assignments.
Part 2, 20 assignments.
3 hours Engineering credit if 5 assignments are done in residence.

Course 22. Shop Mathematics. Advanced course.
20 assignments.

Course 23. Works Management.
16 assignments, 2 hours Engineering credit.

For more detailed information as to these courses, write to the Director of University Extension Division for the regular bulletin.

SECOND GROUP: VOCATIONAL COURSES.

The following special courses, or groups of studies, are now being offered. Others will be added as the need develops. Each one is planned to meet the needs of boys and young men who are working in the lines indicated and who wish to secure some theoretical knowledge and to acquire the ability to make and read drawings connected with their work. The subjects should be taken in approximately the order given in each course, two studies being taken together. That is, a student should start with Mathematics and Drawing together. Then, as one study is completed the next in the list should be begun. Those who have had High School Mathematics might enroll first in more advanced work, but such cases will be handled by special arrangement. Mature men who so desire may take the drawing alone, but all are urged to start with the mathematics, which will be modified to meet the needs of men in each group.

Each study is described in detail on following pages of this Bulletin. University credit is not given.

Course A. For apprentices and employees in railroad shops, garages, and general machine shops.

No.	*Subject.*	*No. of assignments.*
1.	Shop Mathematics:	
	(*a*) Arithmetic and Practical Mchanics	20
	(*b*) Algebra, Geometry, Trigonometry, and Logarithms (optional)	20
2.	Drawing:	
	(*a*) Free-hand	10
	(*b*) Mechanical	10
40.	Bookkeeping and Accounting	10
3.	Machine Drafting	20
10.	Elements of Chemistry	10
11.	Materials of Machine Construction	10
41.	Factory Accounting (optional)	10
21.	Gas, Gasoline and Oil Engines	10
22.	Automobile Engineering	10

Course B. For apprentices and workers in the carpenter's trade.

No.	*Subject.*	*No. of assignments.*
1.	Shop Mathematics	20
2.	Drawing:	
	(*a*) Free-hand	10
	(*b*) Mechanical	10
3.	Machine Drafting (optional)	10
4.	Architectural Drawing	20
5.	Architectural Design	20
6.	Elements of Graphic Statics	10
12.	Materials of Building Construction	10
40.	Bookkeeping and Accounting	10
42.	Cost Keeping for Contractors	10
43.	Law of Contracts (optional)	10

More Architectural Drawing and Design will be given if desired.

Course C. For power plant engine room men.

No.	*Subject.*	*No. of assignments.*
1.	Shop Mathematics	20
2.	Drawing:	
	(*a*) Free-hand (optional)	10
	(*b*) Mechanical (optional)	10
20.	Steam Engineering:	
	Part 1. Fuels and Heat	10
	Part 2. Boilers	10
	Part 3. Engines and Turbines	10
	Part 4. Condensers and Pumps	10

No.	Subject.	No. of assignments.
21.	Gas, Gasoline and Oil Engines (optional)	10
24.	Engine Calculations: Power and Economy	10
25.	Engine Valve Gears and Governors (optional)	10
27.	Engine Room Practice	10
40.	Bookkeeping and Accounting (optional)	10
28.	Power Plant Records	10
29.	Direct Current Electricity:	
	Part 1. Theory	10
	Part 2. Machinery Application	10
30.	Alternating Current Electricity:	
	Part 1. Theory	10
	Part 2. Machinery Application	10
31.	Switchboard Construction and Handling Apparatus	10

NOTE.—The drawing should be taken if the student desires to take Valve Gears and become able to design slide valves.

Course D. For power plant boiler room men.

No.	Subject.	No. of assignments.
1.	Shop Mathematics	20
20.	Steam Engineering:	
	Part 1. Fuels and Heat	10
	Part 2. Boilers	10
	Part 3. Engines and Turbines	10
	Part 4. Condensers and Pumps	10
10.	Chemistry (boiler room questions)	10
23.	Boiler Calculations: Power and Efficiency	10
26.	Boiler Room Practice	10
40.	Bookkeeping and Accounting (optional)	10
28.	Power Plant Records	10

Course E. For coal and salt miners.

No.	Subject.	No. of assignments.
51.	Mine Accidents: Causes and Prevention	15
52.	Origin and Occurrence of Coal	10
58.	Origin and Occurrence of Salt (optional)	10
53.	Explosives	10
54.	Mining Methods	10
55.	Ventilation of Mines	10
60.	First Aid and Rescue Work (special work)	
56.	Haulage and Hoisting	10
40.	Bookkeeping and Accounting (optional)	10

Men engaged in any lines of mining work may take the above subjects, or any portion of them. Young men who are looking forward to the position of pit boss will find much of it to be of great value to them. Any one so desiring may enroll in studies in English language, mathematics, and other subjects.

DESCRIPTION OF VOCATIONAL STUDIES.

GENERAL PURPOSE.

Each study has a certain value of its own and can be taken alone unless some other one is necessary as preparation for it. It is hoped, however, that students will plan to take the grouped studies in practical conformity with the courses given on the preceding pages.

All students are supposed to be employed in regular daily work, in which they are getting practical experience and the real work of their trades. These studies are for the purpose of giving theoretical principles of the work and should help to bring alvancement. They are to tell *why* things are so. They will give the knowledge necessary to make calculations and drawings pertaining to work under way, to do systematic accounting of costs, to provide for safety, and to find more efficient means for doing work. Some of the studies are calculated especially to give an acquaintance with magazine articles and methods employed in other parts of the industrial field, and others to guide in business transactions.

METHODS OF INSTRUCTION.

In most of the work instruction is by correspondence. The instructors are in Lawrence, and each student reports in a personal way, by mail, to the man in charge of the study, addressing all mail to the Director of University Extension. Assignments of work, one or two lessons at a time, are mailed to the student in a similar manner.

Where several students are employed in a single shop or plant, however, classes are formed when possible, with some competent person in charge, the class meeting at fixed times, thus giving each member some personal assistance and stimulus to an active continuance of his work. It is hoped that employers of apprentices will see fit to give a few hours of each week for this work, especially for the drawing. When students in a single city are scattered among several shops or plants, an effort is made to secure a meeting place for the class in the Y. M. C. A., or a city school building.

OTHER STUDIES.

The University Extension Division is ready to take students in studies other than those listed as vocational. High school

subjects given by correspondence are: English, Latin, German, French, History and Psychology.

It is suggested especially that students consider studying English language courses in this way. For detailed information write the Director for the regular Extension Bulletin.

THE ASSIGNMENT.

The regular instructor in each study makes out the assignment or lesson, to guide the student in his work. Sometimes a textbook is used, and the assignment indicates the amount of reading to be done, problems to be solved, and the topics which are to be written up for the report. Sometimes the assignments are printed separately and are the only material given for study. Only two are sent to a student at one time. With this arrangement the student may have one on which he may work at all times while the other is in the mail, provided each assignment when completed is mailed back to the Extension Division promptly. One assignment is supposed to call for about six hours of actual work in study, report writing, etc. No University credit can be given.

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1. SHOP MATHEMATICS.

This is a fundamental study and should be taken first by all who have not had high school mathematics. Its textbooks are written very differently from usual school mathematics books and will be found interesting and practical.

Outline.

Part (a). Arithmetic.

Common and decimal fractions; percentage; ratio and proportion; square and cube root; powers; explanation and interpolation of mathematical tables of circles, powers and roots.

Practical Mechanics.

Circumference of circles; pulleys and gear trains; levers; tackle blocks; inclined plane, and jack screw; work, power and energy; horsepower of belting; horsepower of engines; mechanics of fluids; heat, shrink fits; strength of materials. 20 assignments.

Part (b). Algebra.

Formulas. Explanation of terms, addition, subtraction, multiplication, division, and use of brackets. Transformation of formulas. Solution of simple, simultaneous and quadratic equations; tables and curves. Equations of curves.

Geometry.

Geometrical constructions: parallel lines; perpendiculars; bisectors; angles; chords; regular polygons. Areas of plane figures; properties of

the triangle, rectangle, square, parallelogram, etc. Volumes and surfaces of solids: prisms, cylinders, pyramids, cones, spheres, etc.

Trigonometry.

Ratios, tangent, cotangent, sine, cosine, secant and cosecant. Use of these functions in connection with screw threads and spirals. Solution of triangles. Application to problems on heights and distances in connection with jig and fixture work. Solution of problems in spiral, sprocket, and gear milling.

Logarithms.

Definitions; mantissa; characteristic, use of tables; multiplication, division, powers and roots. Explanation and examples of slide rule practice. 20 assignments.

All illustrations from the practical field employed in the above study will be chosen to fit the vocation of the student. For example, in practical mechanics, purely machine trade applications will be omitted and applications of the square, of board measurement and of simple formulas on stresses will be substituted in the carpenter's course. In power plant courses an application of engineering formulas and the use of tables in engineering handbooks will be substituted.

2. DRAWING.

All who wish to acquire ability to read and use drawings of machines or construction plans, or to make such drawings and designs, should begin with this work. It is planned also to give some proficiency in free-hand sketching.

Outline.

Part (a). Free-hand Drawing.

Includes free-hand lettering, sketching, and isometric and orthographic sketching of simple machine parts. 10 assignments.

Part (b). Mechanical Drawing.

Study of orthographic projection with reference to machine parts; correct relation of views to one another; weights of lines; proper methods of inking plates; dimensioning parts; reading and making blue prints.
10 assignments.

The outfit of drawing instruments and supplies of paper, pencils, ink, etc., is described in a later page. Information is given there as to the cost and the methods for ordering.

3. MACHINE DRAFTING.

This is a continuation of the Mechanical Drawing, intended primarily for employees in machine and railroad shops who wish to become more expert in the making of simple drawings.

Outline.

Drawing of machine parts selected in accordance with the work of the student, with special attention to correctness of projections, dimensions and lettering; shade lines, section lining; tracing; blue-printing; standard forms of fastenings; assembled drawings. 10 or 20 assignments.

4. ARCHITECTURAL DRAWING.

This is intended to make the student familiar with the methods of drawing and representing timber joints and many other details in house building. It should be preceded by the first work in drawing and is pre-

paratory to the following subject of Architectural Design. Those who wish to become able to read and understand architects' building plans will find this work profitable.

Outline.

Drawing of details of building construction from sample plates; methods of framing; construction of window frames and sashes; exterior and interior woodwork. 20 assignments.

5. ARCHITECTURAL DESIGN.

This is a continuation of number 4 and is intended to give more definite instruction in preparing complete house plans and suggestions in house planning.

Outline.

Working drawings; methods of framing; house planning; bills of material; cost estimates. 20 assignments.

6. ELEMENTS OF GRAPHIC STATICS.

Those who wish to become able to analyze the forces and stresses occurring in roofs and roof trusses and in the different parts of simple bridges should take this work. Before doing so, it is necessary to do Part (a) of Shop Mathematics and Free-hand and Mechanical Drawing. It is desirable that Part (b) of Shop Mathematics should be taken also.

Outline.

Representation of forces by lines; composition and resolution of force systems; conditions of equilibrium; dead loads; wind loads; analysis of stresses in simple truss members. 10 assignments.

10. ELEMENTS OF CHEMISTRY.

In order to understand much of the work in connection with combustion of fuels and in the manufacture of iron and steel, a knowledge of some simple elements of chemistry is necessary. The study indicated here is similar to the first course in chemistry given regularly in the University but is cut down in amount so as to give only the prime essentials. It is an important subject and should be taken by all who wish to make any real beginning in science study.

Outline.

Fundamental principles. Most important chemical elements and their combining weights; most important laws of chemical combination; a few typical compounds. 10 assignments.

11. MATERIALS OF MACHINE CONSTRUCTION.

This subject calls for a previous knowledge of chemistry and is an important one for those who are working in machine shops and foundries. It deals with the processes of manufacture of different materials used in the construction of machines and of the steel used for tools.

Outline.

Occurrence of iron ore in the United States; smelting of the ore; blast furnace processes, giving different grades of pig iron; puddling process for wrought iron; properties of cast iron and malleable iron; the Bes-

semer and open hearth steel furnaces; rolling mill processes; forging composition metals, brass, bronze, babbitt, etc.; tool steels.

10 assignments.

12. MATERIAL OF BUILDING CONSTRUCTION.

For those who are engaged in carpentry work or other lines of building construction, a knowledge of the properties of the materials used and of simple methods of calculating the strength of beams and columns is very desirable. A brief treatise of this subject is given here, and this study is included in the group for carpenters.

Outline.

Study of the manufacture and properties of the principal materials used in building construction; fundamental principles of the mechanics of materials; strength of beams and columns. Materials dealt with are timber, steel, iron, brick, stone and concrete. 10 assignments.

20. STEAM ENGINEERING.

The subdivisions of Steam Engineering listed below are designed to give to the man acquainted with the operation of engines and boilers an abridged course of study that will render him more competent to solve the problems that come to him and to operate more intelligently the plant under his care.

Outline.

Part 1. *Fuels and Heat.* A study of the magnitude and location of fuel fields; general classification of fuels; determination of their composition (ash, carbon, etc.), and heating value; the general laws and conditions for perfect combustion; the measurement of temperatures and the practical heat unit; effects and nature of heat. 10 assignments.

Part 2. *Boilers.* General types of boilers, their accesssions and automatic features, stokers, continuous recorders, etc. Proper proportions of heating surface, grate surface and stack area; boiler troubles and remedies; steam piping; amount of heat to generate steam; equivalent evaporation; boiler horsepower; treatment of feed waters; cost of generating steam. 10 assignments.

Part 3. *Engines and Turbines.* Types and kinds of engines and turbines; engine efficiency and economy; the engine indicator and its use; horsepower calculations; relation between electrical and mechanical power; calculations of steam consumption; general care of engines; advantages of reciprocating and rotary engines. 10 assignments.

Part 4. *Condensers and Pumps.* Classification of kinds and types of condensers and pumps; uses to which various forms may be applied; effect of condensing equipment on engines; condensing plant auxiliaries; calculations of condensers and pump sizes; duty of pumps.

10 assignments.

21. GAS, GASOLINE, AND OIL ENGINES.

The gas and oil engine has taken a position of great importance in the business world. One of its most important applications is that of the gasoline engine in automobile and auto truck service. It rightfully claims a place in the study of power plant machinery, as well as in the

automobile industry. This study is one dealing with the fundamental principles of the engine, and is one which men interested in any kind of engine application should take first.

Outline.

Classification and description of types of engines in common use; fuels; air required with fuel in an engine cylinder; the Otto gas cycle; temperature of combustion; methods of ignition; lubrication.

10 assignments.

22. AUTOMOBILE CONSTRUCTION.

This study is planned for the benefit of those working in garages and is included as an optional in the group for shop employees. It has to do mainly with the use and operation of the automobile, rather than with the design.

Outline.

Calculation of power; compression and combustion pressures; ignition; valves; cooling devices; transmission mechanism; consumption of gasoline; lubrication. 15 assignments.

23. BOILER CALCULATIONS: POWER AND EFFICIENCY.

Boiler room men will find this a practical study in boiler room tests. During the assignments a proximate analysis of coal and flue gas, a determination of fuel comsumption, of losses from imperfect combustion, of the amount of water, the quality of steam, etc., will be conducted by the student, who will be asked to prepare a report on these conditions as found in the boiler room in which he is employed.

Outline.

Discussion of elements affecting the power and efficiency of steam boilers. Definitions; units; total heat; quality of steam; equivalent evaporation. Flue gas analysis; apparatus and method; excess air coefficient; losses with excess air; losses with imperfect combustion. Smoke: cause and prevention.

Determination of amount of fuel and water; sampling fuel; other readings to be taken; quality of steam; apparatus and methods; proximate analysis of coal; heat value from same; heat value of coal by Pair calorimeter; routine of test; methods; readings.

Preparation of the report. Working up of the results of tests; final report. 10 assignments.

24. ENGINE CALCULATIONS: POWER AND EFFICIENCY.

Following the completion of the work in Steam Engineering, this study is offered to engine room men as a means of enabling them to conduct practical engineering laboratory tests for the power and efficiency of the engines under their care. During the work each student must make practical engine tests, perform all necessary calculations, and prepare the final report on the plant in which he is employed.

Outline.

Methods of testing under different conditions; definitions and units; instruments used, and their standardization; indicator reducing motions; Prony brake; rheostats.

Routine of test; readings and methods for taking same.

Preparation of the report. Working up the results of the test; calculation for horsepower and efficiencies; allowances for auxiliaries; final report. 10 assignments.

25. VALVE GEARS AND GOVERNORS.

For engine room men and draftsmen this work offers an excellent study of valve gears and governors. The former can supplement his practical knowledge by an application of the theory presented and the latter can equip himself for actual design in this field.

Outline.

Types of slide valves and driving mechanism; types of Corliss valves and driving mechanism; definitions of terms used; events of stroke; Bilgram diagram for slide valve; governing by throttling; governing by changing point of cut-off. Pendulum governor; application to slide valve; application to Corliss valve. Shaft governor: types; action; riding valve; Meyer valve gear; Bilgram diagram for variable cut-off; setting slide and Corliss valves. 10 assignments.

26. BOILER ROOM PRACTICE.

This is a study of general boiler room equipment and methods of operation. Its aim is to give a knowledge of best conditions as they exist in up-to-date plants, and the material for study will be taken quite largely from engineering magazines. Special articles will be studied and are to be discussed by the student with reference to the conditions in their own plants. It will be a study of methods and economic conditions, which may be taken by those who do not care to do the routine technical work of the other studies.

Outline.

Types of boilers, with study of conditions to which each is adapted; safety, with study of causes of explosions; automatic stokers, with study of conditions where they produce savings; the economizer; natural draft *versus* mechanical draft; boiler room efficiency. 10 assignments.

27. ENGINE ROOM PRACTICE.

This has the same relation to the engine room conditions that number 26 has to boiler room conditions.

Outline.

History of development of steam power generation; engine types, high speed, Corliss, special types, turbines; power rating of engines; the economical cut-off; condensing *versus* noncondensing plants; selection of engines for a variable load; the internal combustion engine as an economical type for small plants and for special locations; the cost of power. 10 assignments.

28. POWER PLANT RECORDS.

The keeping of records of performance in the power plant is coming to be recognized more and more as the distinguishing mark of the up-to-date engineer. Current magazines have given much attention to this, recently, and in this subject for study the best practice of modern plants will be dealt with in a very complete manner.

Outline.

Study of reasons for keeping records, and of the quantities which should be recorded; forms used in best modern plants for recording data; meters and other instruments used to determine amounts of fuel, water, oil and other stores used and power generated; study of this data and of methods for presenting results of performance in forms to be of use in regular operation of the plant. 10 assignments.

29. DIRECT CURRENT ELECTRICITY.

This subject, together with numbers 30 and 31 following, is laid out for the purpose of giving to the operating engineer a working knowledge of the electrical machines and equipment which he is handling.

Outline.

Part (a). Theory.

Elementary principles underlying the processes of the generation of direct current and the laws which govern the flow of direct current in electrical conductors; laws of the magnetic circuit; designing of electro-magnets. 10 assignments.

Part (b). Application.

Construction and operation of generators and motors; operation of direct current power plants; design and construction of direct current distributing systems. 10 assignments.

30. ALTERNATING CURRENT ELECTRICITY.

Outline.

Part (a). Theory.

Laws governing the generating of alternating currents; flow of current in alternating current circuits; principles involved in the operation and performance of alternating current motors. 10 assignments.

Part (b). Application.

Construction and operation of alternators, transformers and motors; methods of transmitting and distributing electrical power at high voltage. 10 assignments.

31. SWITCHBOARDS AND CONTROLLING DEVICES.

Outline.

The switchboard panel and its function; functions of various controlling devices; details of connections; standard switchboard construction; study of handling methods. 10 assignments.

40. BOOKKEEPING AND ACCOUNTING.

In the newer development of industrial work accounting has come to be of greater importance than in former years. It goes farther than the mere keeping of books, and must have a bearing upon the cost-keeping systems employed and, in an indirect way, upon the methods employed in manufacture. All portions of a plant feel this influence, and it is essential that all who aim to have a full understanding of any part of the work should be familiar with the methods employed in the accountant's office. The work offered here teaches the fundamental principles of those forms of bookkeeping most used in industrial plants and seeks to define the various terms used. Problems and exercises are made to conform as closely as possible to the work which the student has in hand.

Outline.

Consideration and definition of accounts, merchandise, cash, capital, profit, etc.; principles of double-entry bookkeeping; the purpose of a double set of accounts; debit and credit; explanation of the cash book, invoice book, purchase book, bill book, day book, journal, ledger, etc.; opening and closing double-entry books; trial balance; the formation of the balance sheets and preparation of statements; single-entry bookkeeping, passing from single to double entry; a brief examination of accounting systems. 10 assignments.

41. FACTORY ACCOUNTING.

This work is offered to young men who have completed the work in shop mathematics and bookkeeping and accounting and who look forward to the supervision of factory departments or the vocation of the cost accountant in manufacturing plants. The object is to provide a thorough and comprehensive analysis of the principles of cost accounting by an investigation of modern cost systems and their methods of eliminating unnecessary expense, and in this way enabling the student to develop special systems to fit particular situations. Knowledge of the slide rule is essential.

Outline.

The purposes of a cost system; the various elements of cost; establishing cost-finding units; direct and indirect costs; analysis and distribution; systems of wage payment; power plant expense; storehouse expense; shop expense; depreciation expense; general expense; selling expense; introducing a cost system; choice of blank forms; report checking; general routine; relation of the cost system to the general accounting system; cost charts; progress charts; proper use of reports and statements by the management. 15 assignments.

42. COST KEEPING FOR CONTRACTORS.

This is intended to assist contractors in systematizing construction costs. The fact that the contractor uses a plant which must be shifted as the work progresses, left idle during unfavorable weather conditions, or installed and dismantled at comparatively short intervals, makes his task of accounting an extremely difficult one. The cost-keeping systems

of leading building construction companies will be analyzed and the principles gathered from this investigation used by the student in outlining systems of cost keeping for special situations.

This course can be pursued only by those whose training includes a knowledge of elementary bookkeeping and the application of the slide rule.

Outline.

Cost keeping defined; cost keeping differentiated from bookkeeping; time keeping; report cards; foreman's diary; storekeeper's reports; reports materials and supplies; report checking; fundamental divisions of cost; analysis of direct and overhead expense account; field and office supplies; subcontracts; the use of summary sheets, price records, cost and progress charts, card index, work notes and sketches in estimating building contracts. 10 assignments.

43. LAW OF CONTRACTS.

This is a short study of the fundamental law of contracts relating particularly to engineering construction work. The building laws of the state will be given full treatment, and the subject is one which those who are having to do with the erection of buildings would take with profit.

Outline.

The nature of contracts in general; contract essentials; agency; independent contractors; subcontracts; real property; deeds; easements; rights of contractors; bonds; liens; interpretation of specifications.

10 assignments.

51. MINE ACCIDENTS: CAUSES AND PREVENTION.

Description. The study deals principally with mine explosions, giving their causes and the precautions which should be taken to prevent them. Some attention is also given to other forms of accidents, such as suffocation and electric shock.

Outline.

Comparison of number of accidents in this and other countries, with reasons; causes of accidents; explosions, gas, dust, explosives; precautions; suffocation; electric shock.

52. ORIGIN AND OCCURRENCE OF COAL.

This deals with matters which are fundamental to the coal-mining industry. It deals in the main with the distribution, properties, and the commercial handling of coal, giving a great amount of information valuable to those connected with the industry.

Outline.

Geographic extent of coal and its distribution in the United States and in the world; output and value of coal in the United States and in the world; chemical and physical properties; geological formations in which coal is found; origin of coal. 10 assignments.

53. EXPLOSIVES.

Intended to give information concerning the manufacture and composition of explosives, the uses to which each kind is suited, and the proper methods of handling them.

Outline.

Black powder; dynamite; safety powders; composition and manufacture; characteristics; proper uses; methods of firing; precautions to prevent accidents. 10 assignments.

54. MINING METHODS.

A discussion of the methods of mining deposits occurring in beds, such as coal and salt.

Outline.

Bed deposits; character of top and bottom; long-wall methods; room-and-pillar methods; reasons for use of different methods.

10 assignments.

55. VENTILATION OF MINES.

A study of the necessity of artificial ventilation, and the methods of producing and controlling ventilation and the measurement of air currents.

Outline.

Mine gases, their occurrence, detection and effects; natural ventilation; furnace ventilation; fan ventilation; the arithmetic of ventilation; safety lamps. 10 assignments.

56. HAULAGE AND HOISTING.

The methods of hauling on level and inclined roads by animals and machinery, and the methods of hoisting from shafts.

Outline.

Cars; track in rooms and entries; mule haulage; motor haulage; rope haulage; shaft bottoms; hoisting in cages and skips; automatic cages; hoisting rope; hoisting engines and motors. 10 assignments.

58. ORIGIN AND OCCURRENCE OF SALT.

This to the salt miner has the same value as No. 52 has to the coal miner. It should be chosen by those preparing themselves for the salt industry.

Outline.

Geographic distribution of salt in the United States and in the world; output of salt in the United States and in the world; chemical and physical properties; geological formations in which salt is found; origin of salt. 10 assignments.

60. FIRST AID AND RESCUE WORK.

The University has secured the coöperation and the equipment and staff of one of the mine rescue cars owned and operated by the federal Bureau of Mines. Arrangements will be made for all students who enroll in this work to be given instruction in the use of the apparatus and the first aid, usually under the supervision of the government experts. One of the cars is stationed regularly in the Kansas-Oklahoma territory, and students will find the opportunity to secure this specialized instruction to be of great interest and value to them.

Since this work will be carried out in coöperation with the Federal Bureau officials, it will be necessary to conform to the schedules of the car, and the instruction will be given by special arrangement instead of by the regular method of fixed assignments.

METHOD OF ENROLLING, FEES, OUTFIT EXPENSES.

The person who wishes to take up the work in any course outlined on the preceding pages, or who wishes to take any of the individual studies, should make up his mind definitely as to the work desired and send to the Extension Division for an application blank. For suggestions and advice as to the studies he should write to the Dean of the School of Engineering. The application blank must be filled out to show which course is being taken and which studies are to be begun first, and then returned with the required fee to the Director of the Extension Division.

As soon as his application and the fee have been received, the first lesson assignment will be sent and the work thus begun in regular fashion. The student should endeavor to do the work of each assignment promptly and mail his report to the Extension Division without delay, in order that there may be no breaks to lessen the effectiveness of the study. The student is urged to write asking for information on any points, but, of course, he should consider carefully each point and not ask questions which he could work out for himself by a little thought.

FEES. The only amount charged for the Correspondence-Study work is the incidental fee of $10 a year for residents of Kansas, or $15 for nonresidents. This is the same amount charged regular students of the University. It is less than the actual expense required to carry on this kind of instruction, and the student thereby receives a certain direct benefit from the public funds devoted to the support of the University which are applied to the maintenance of this line of work. The fee may be paid in two installments of $5 each, the first to be sent with the application blank and the second one month after work begins.

The incidental fee covers a period of one year, beginning on the date when the work is begun, and is without reference to the number of studies taken or completed. If the student enrolls for two subjects at the beginning, he may begin others as soon as the first are completed, and make his work continuous, without additional cost.

Money should be sent by postal or express money order or by Kansas City or Chicago draft, made payable to the University of Kansas.

OUTFIT EXPENSES. The first assignment in each study is accompanied by a full statement of books, instruments and material required. In some studies textbooks are used, and the cost of the book for such a study may be the only expense connected with it. In others, especially in Drawing, instruments and working material may amount to a considerable item.

The following list of materials is required for the first twenty assignments in Free-hand and Mechanical Drawing. Much of this material will be found to apply also on the more advanced work in Machine Drafting:

1. French's Engineering Drawing. (Textbook.)
2. A short set of Richter's instruments, including one compass, with pen, pencil and two needle attachments, and one handle to use with pen and pencil attachments; one box of 4H leads, also lengthening bar.
3. One leather case, pocketbook style, for above.
4. Sixteen sheets of one-eighth-inch cross-section paper, 9″ x 12″.
5. Pencils: Kohinoor, one 3H and one 4H.
6. Erasers: One typewriter, and one soft pencil.
7. Sandpaper, in pad, for sharpening pencils.
8. Penholder.
9. Pen points: six each of Gillott's 303, bank, and ball point.
10. One bottle Higgins' black ink.
11. Pen wiper: chamois skin.
12. Two blotters.
13. Drawing board, 12″ x 18″ x 1″.
14. Tee square, 9″ head, 18″ blade.
15. Two transparent triangles, good weight 30°-60°, 10½″ hyp. and 45°, 7″ hyp.
16. One 12″ triangular architect's scale.
17. One good ellipse curve.
18. Sixteen sheets brown detail paper, 9″ x 12″.
19. One dozen small thumb tacks.
20. Sixteen sheets tracing cloth, 9″ x 12″.

The articles in this list may be purchased at many good book and writing material supply stores, but in some towns this may not be possible. As the goods are retailed, the total cost amounts to about thirteen dollars. Arrangements have been made with the principal supply stores carrying material for the especial use of University students in Lawrence whereby the full outfit may be ordered and be sent by parcel post, postage paid, for $10.65. Write to the Dean of School of Engineering for further particulars.

SUMMER WORK AT THE UNIVERSITY.

In planning for the vocational studies outlined in the foregoing bulletin, no requirements have been considered calling for work of a strictly laboratory nature, everything being intended for home study or study in connection with the regular employment of the student. Work in the summer, during the two weeks immediately following the close of the regular University year, may be provided for those students who desire it. This work will be in the laboratories and shops of the University, and so planned that it will be adapted to the needs of those who take it.

For illustration, students who are employed in railroad shops and other machine shops may do practical work in pattern shop and foundry if their regular work has not given them experience in this line, and they may also learn to make boiler and engine tests, handling the engine indicators and calculating horsepower with the steam laboratory equipment which is available. All who desire to do this are requested to make application to the Dean of the School of Engineering, and if a sufficient number desire it the arrangement will be carried out.

This summer work will have a connection with the regular Summer Session of the University, and an additional fee will be required. Complete information on this point will be given as soon as it is known whether there will be sufficient demand to warrant the establishment of the work.

ADMISSION TO THE UNIVERSITY.

Requirements for the School of Engineering.

For the benefit of persons who contemplate residence study at the University for a degree, in addition to correspondence instruction, the following general facts are briefly given:

SUBJECTS FOR ADMISSION.

Fifteen units must be offered for entrance. Of these, nine must be those in the list of required subjects, the other six being selected from the optional list. Selection from this optional list is unrestricted, excepting that one unit only may be offered from the group of six subjects listed last in the column.

REQUIRED.

Mathematics 1, 2, 3, algebra and plane and solid geometry	3 units.
English 1, 2, 3	3 "
Physics	1 "
Foreign language—Two units in one of the following: French, German, Latin or Spanish	2 "
Required	9 units.

OPTIONAL.

Latin 1, 2, 3	– units.
German 1, 2, 3	– "
French 1, 2, 3	– "
Greek 1, 2, 3	– "
Spanish 1, 2	– "
Greek and Roman history	1 "
Mediæval and modern hist.	1 "
English history	1 "
American history	1 "
Chemistry	1 "
Higher algebra	½ "
Plane trigonometry	½ "
Physical geography	½ or 1 "
Botany	1 "
Physiology	1 "
Zoölogy	1 "
Biology	1 "
Economics	½ or 1 "
Civics	½ "
Advanced arithmetic, if taken after first year of algebra	½ "
Free-hand or mechanical drawing	1 "
Manual training	2 "
One unit only may be offered from the following group:	
Stenography	½ "
Bookkeeping	½ "
Commercial law	½ "
Commercial geography	½ "
Agriculture	½ or 1 "
Psychology	½ "

An entrance unit represents five periods a week, of not less than forty minutes each, for thirty-five weeks.

ENTRANCE WITHOUT FOREIGN LANGUAGE.

High-school graduates presenting fifteen units from the list of accredited entrance subjects, but with no foreign language, will be admitted to the School of Engineering without entrance conditions, but will be required to take two full years of German, French or Spanish in the University, instead of the one year of foreign language regularly required.

ADVANCED CREDIT IN FOREIGN LANGUAGE.

Advanced credit for work in preparatory schools will be given upon examination only, excepting for the following provisions in foreign language: Graduates of high schools presenting four units in not more than two foreign languages, one of these being in a modern language, will be allowed to substitute five hours of optional subjects in the University for five hours of the regularly required modern language in the engineering courses of study. When presenting five or more units in not more than two foreign languages, two of these units being in a modern language, they will be allowed to substitute ten hours of optional courses for the ten hours of modern language regularly required. The choice of these optional courses shall be subject to the approval of the student's adviser and the Dean of the School of Engineering. For times and places of examination for advanced credit, write to the Registrar of the University.

ADMISSION TO ADVANCED STANDING.

For an advanced rank, the applicant must have completed all of the courses of the curriculum below the rank for which he applies, including the entrance requirements, or their substantial equivalent, as determined by the committee on advanced standing. Application for credits toward advanced standing should be made to the Dean of the School of Engineering.

SPECIAL STUDENTS.

Opportunity is given in the School of Engineering for the admission of persons of mature years who desire to pursue some special lines of work, without following any prescribed course of study or becoming candidates for a degree.

The admission of such special students is directly under the control of the Dean of the School of Engineering, whose certificate of acceptance must be presented to the Registrar before registration.

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ENGINEERING BULLETIN No. 5.

WATER SUPPLIES OF KANSAS.

Part I.—Ground Water Supplies.

BY

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of the Engineering Departments.

The Station designs to issue bulletins, of which this is the third number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

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WATER SUPPLIES OF KANSAS.

Part I. Ground Water Supplies.

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Director Water and Sewage Laboratory, State Board of Health.
UNIVERSITY OF KANSAS.

INTRODUCTION.

For some time the necessity of a compiled list of the waterworks plants in Kansas, with descriptions of the main features of each plant, and, perhaps, certain other information concerning their construction, equipment and operation, has been apparent from the many inquiries received each year at the University from waterworks superintendents, engineers, municipalities, and other interested citizens considering the construction of waterworks plants.

On account of the fact that the State Board of Health and the University, through the Engineering Department and the Water and Sewage Laboratory, are working with the water-supply problems of the state, examining plans, consulting with interested parties for new plants and improvements to existing plants, and looking after the sanitary quality of the water furnished by the plants, the task of actually getting together all of this material seems to fall upon them.

The advantage of having information of this sort gathered into one volume is realized, but on account of the great mass

of detail to be covered, and on account of the lack of time to gather material, it has been decided to publish the information in two parts, one treating particularly of the ground water supplies and the other of the surface water supplies. This volume, therefore, will describe the ground water supplies only, the surface water supplies being left for an additional volume which will appear some time during the summer of 1915.

An ideal work of this kind would cover completely a great many points which we have merely touched upon on account of the difficulty of collecting such material and keeping it up to date, due to the large number of waterworks plants in the state and the constantly changing officials, the reluctance of some and the inability of other authorities to answer questions or furnish information. The information which does appear was secured from the records of the State Board of Health, from personal visits of members of the staff of the Division of Water and Sewage and answers to letters which have been sent to the authorities in charge of each waterworks plant.

CHAPTER I.

CLASSIFICATION OF WATERWORKS PLANTS.

The most common classification of waterworks plants is that which takes into consideration the source of supply. The most natural method of classifying would be that which divides the whole number of plants into two classes, depending upon whether ground or surface water is used. Those plants using ground water may be subdivided into deep wells, shallow wells and springs, while those using surface water may be divided into rivers and streams, natural lakes and ponds, and impounded supplies. In this classification the distinction between the divisions must be more or less arbitrary. Deep wells and shallow wells must overlap in some cases. For instance, we are accustomed to calling deep wells those which are 75 to 100 or more feet in depth and which pass through an impervious layer of material before reaching the water-bearing strata. Shallow wells, which supply the largest majority of the cities in the state, are those which secure water at a depth of less than 75 to 100 feet and which may be subject to contamination by surface influences.

There is no difficulty in classifying such supplies as those

from the deep wells of Pittsburg, Girard, Columbus, Mineral, Scammon, Mulberry and Chetopa, and others in the southeastern part of the state which secure water at a depth of approximately 500 to 1000 feet, but those supplies are in no way similar to the supplies of Colby, Goodland, Wa Keeney, Oakley, Syracuse and some others in the western part of the state, which secure water at a depth of 100 to 200 feet; yet the deep wells of the latter-named cities are not affected by surface influences. They are separated from surface water by an impervious strata and should certainly not be classified as shallow wells.

A classification of streams and impounded supplies must overlap. For instance, Garnett, Horton, Osage City and Yates Center have supplies from large reservoirs formed by damming small dry-weather streams. Washington, Jewell City, Olathe and Pleasanton have supplies from impounding reservoirs formed by damming somewhat larger streams. Russell* is supplied from a reservoir formed by damming one branch of the headwaters of the Smoky Hill river. Still, many of the plants using rivers or large streams as sources of supply find it necessary to construct dams across the streams in order to insure a supply during extremely dry weather. Examples may be found at Coffeyville and Independence on the Verdigris river, at Emporia and Iola on the Neosho river, at Fort Scott on the Marmaton, and at Ottawa on the Marais des Cygnes river. This classification is the one which has been used in Table I, which contains, alphabetically arranged, the cities of the state supplied with water; the population from the 1910 United States Census; the source of supply, whether deep wells, shallow wells, springs, river water, creek water, or impounded water; and the ownership of the plant.

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* Since August, 1914, Russell has been supplied from wells driven in the dry bed of their impounding reservoir.

TABLE I.

List of Cities in Kansas Having Waterworks.

City.	*Pop. 1910.*	*Type.*	*Ownership.*
Abilene	4,118	Springs	Public.
Almena	702	Shallow wells	Public.
Alton (not built)	414	Shallow wells	Public.
Altoona	1,462	Shallow wells	Public.
Anthony	2,669	Shallow wells	Public.
Arkansas City	7,508	Shallow wells	Public.
Ashland	910	Shallow wells	Public.
Atchison	16,429	Missouri river	Private.
Atwood	680	Shallow wells	Public.
Augusta	1,235	Walnut river	Public.
Baldwin	1,386	Springs	Public.
Baxter Springs	1,598	Deep wells	Private.
Belle Plaine	849	Shallow wells	Public.
Belleville	2,224	Deep wells	Public.
Beloit	3,082	Shallow wells	Public.
Bennington	386	Shallow wells	Public.
Blue Rapids	1,756	Shallow wells	Public.
Bonner Springs	1,462	Shallow wells	Public.
Bucklin	696	Deep well	Public.
Bunker Hill	282	Springs	Public.
Burden	424	Springs	Public.
Burlingame	1,422	Dragoon creek	Public.
Burlington	2,180	Neosho river	Public.
Burr Oak	1,132	Shallow well	Public.
Caldwell	2,205	Shallow wells	Public.
Caney	5,061	Cana river	Public.
Cawker City	870	Shallow wells	Public.
Cedarvale	948	Cana river	Public.
Chanute	9,272	Neosho river	Public.
Chapman	871	Shallow wells	Public.
Cherokee	1,452	Deep well	Public.
Cherryvale	5,572	Verdigris river	Public.
Chetopa	1,548	Deep well	Public.
Cimarron	587	Shallow wells	Public.
Clay Center	3,438	Shallow wells	Public.
Clearwater	569	Shallow wells	Public.
Clifton	614	Shallow wells	Public.
Clyde	1,057	Shallow wells	Public.
Coffeyville	12,687	Verdigris river	Public.
Colby	1,130	Deep well	Public.
Coldwater	684	Shallow wells	Public.
Columbus	3,064	Deep wells	Public.
Concordia	4,415	Shallow wells	Public.
Conway Springs	1,292	Springs	Private.
Cottonwood Falls*	899	Shallow wells	Public.
Council Grove	2,545	Neosho river	Private.
Delphos	767	Shallow wells	Public.
Dodge City	3,214	Shallow wells	Public.
Douglas	657	Walnut river	Public.
Downs	1,427	Shallow wells	Public.
El Dorado	3,129	Wells and infiltration gallery	Public.
Ellinwood	976	Shallow wells	Public.
Ellis	1,404	Shallow wells	Public.
Ellsworth	2,041	Shallow wells	Public.
Emporia	9,058	Neosho river	Public.

* Supplied from Strong City.

City.	*Pop. 1910.*	*Type.*	*Ownership.*
Englewood	518	Shallow wells	Public.
Enterprise	706	Shallow well	Public.
Erie	1,300	Shallow well	Public.
Esbon	347	Shallow wells	Public.
Eureka	2,333	Shallow wells	Public.
Florence	1,168	Shallow well	Public.
Fort Scott	10,463	Marmaton river	Public.
Fowler	473	Deep well	Public.
Frankfort	1,426	Shallow wells	Public.
Fredonia	3,040	Fall river	Public.
Frontenac	3,396	Deep well	Public.
Galena	6,096	Shoal creek	Public.
Garden City	3,171	Shallow wells	Public.
Garnett	2,334	Impounded	Public.
Gas City*	1,281	Neosho river	Public.
Girard	2,446	Deep wells	Public.
Glasco	720	Shallow wells	Public.
Glen Elder	565	Shallow wells	Public.
Goodland	1,993	Deep wells	Public.
Great Bend	5,500	Shallow wells	Private.
Green	289	Shallow wells	Public.
Greenleaf	781	Shallow wells	Public.
Halstead	1,004	Shallow wells	Public.
Hanover	1,039	Shallow wells	Public.
Harper	1,638	Shallow wells	Public.
Havensville	412	Shallow wells	Public.
Hays City	1,961	Shallow wells	Public.
Herington	3,273	Springs	Public.
Hiawatha	2,974	Wells and springs	Public.
Highland	763	Shallow wells	Public.
Hill City	983	Shallow wells	Public.
Hoisington	1,975	Shallow wells	Public.
Holton	2,842	Springs	Public.
Holyrood	361	Shallow wells	Public.
Horton	3,600	Impounded	Public.
Humboldt	2,548	Shallow well	Public.
Hutchinson	16,364	Shallow wells	Private.
Independence	10,480	Verdigris river	Public.
Iola	9,032	Neosho river	Public.
Jamestown	462	Shallow wells	Public.
Jetmore	317	Shallow wells	Public.
Jewell City	839	Impounded	Public.
Junction City	5,598	Shallow wells	Public.
Kanopolis	577	Shallow wells	Public.
Kansas City	85,679	Missouri river	Public.
Kensington	497	Shallow wells	Public.
Kingman	2,570	Springs	Public.
Kinsley	1,547	Shallow wells	Public.
Kirwin	626	Shallow wells	Public.
Kiowa	1,520	Shallow wells	Public.
La Cygne	657	Shallow wells	Public.
La Harpe	2,080	Elm creek	Public.
Larned	2,911	Shallow wells	Public.
Lawrence	12,374	Shallow wells	Private.
Leavenworth	19,363	Missouri river	Private.
Lebanon	731	Springs	Public.
Liberal	1,716	Deep wells	Public.
Lincoln	1,508	Shallow wells	Public.

* Supplied from Iola.

City.	*Pop. 1910.*	*Type.*	*Ownership.*
Lindsborg	1,939	Shallow wells	Public.
Logan	714	Deep well	Public.
Lucas	573	Shallow well	Public.
Luray	341	Shallow wells	Public.
Lyndon	763	Salt creek	Public.
Lyons	2,071	Shallow wells	Public.
McPherson	3,546	Deep wells	Public.
Madison	721	Shallow wells	Public.
Manhattan	7,722	Shallow wells	Public.
Mankato	1,155	Shallow wells	Public.
Marion	1,841	Shallow wells	Public.
Marquette	715	Shallow wells	Public.
Marysville	2,260	Blue river	Private.
Meade	664	Deep wells	Public.
Medicine Lodge	1,229	Elm creek	Public.
Miltonvale	829	Shallow well	Public.
Mineral	1,770	Deep well	Private.
Minneapolis	1,895	Shallow wells	Public.
Moline	808	Shallow wells	Public.
Mound City	698	Sugar creek	Public.
Mound Ridge	626	Shallow wells	Public.
Mulberry	997	Deep well	Public.
Mulvane	1,084	Shallow wells	Public.
Neodesha	2,872	Fall river	Public.
Newton	7,862	Deep wells	Public.
Nickerson	1,195	Shallow wells	Public.
Norton	1,787	Shallow wells	Public.
Oakley	681	Deep wells	Public.
Oberlin	1,157	Deep wells	Public.
Olathe	3,272	Impounded	Public.
Onaga	759	Shallow wells	Public.
Osage City	2,432	Impounded	Public.
Osawatomie	4,046	Marais des Cygnes river	Public.
Osborne	1,566	Shallow well	Public.
Oswego	2,317	Neosho river	Public.
Ottawa	7,650	Marais des Cygnes river	Public.
Oxford	624	Shallow wells	Public.
Paola	3,207	Bull creek	Public.
Parsons	12,463	Little Labette creek	Private.
Peabody	1,416	Shallow wells	Public.
Peru	575	Shallow wells	Private.
Phillipsburg	1,302	Deep wells	Public.
Pittsburg	14,755	Deep wells	Public.
Plainville	1,090	Deep wells	Private.
Pleasanton	1,373	Impounded	Public.
Protection	390	Deep well	Public.
Pratt	3,302	Shallow wells	Public.
Rosedale*	5,960	Missouri river	Public.
Russell	1,692	Impounding reservoir	Public.
Sabetha	1,768	Shallow wells	Public.
St. Francis	492	Shallow wells	Public.
St. John	1,785	Shallow wells	Public.
St. Marys	1,397	Shallow wells	Public.
Salina	9,688	Shallow wells	Public.
Scammon	2,233	Deep wells	Public.
Scandia	579	Shallow wells	Public.
Scott City	918	Deep wells	Public.
Sedan	1,211	Cana river	Public.

* Supplied from Kansas City, Mo.

City.	*Pop. 1910.*	*Type.*	*Ownership.*
Sedgwick	626	Shallow wells	Public.
Seneca	806	Shallow wells	Public.
Sharon Springs	440	Deep wells	Public.
Smith Center	1,292	Wells and infiltration gallery	Public.
Stafford	1,927	Shallow wells	Public.
Sterling	2,133	Shallow wells	Public.
Stockton	1,317	Shallow wells	Public.
Sylvan Grove	464	Shallow wells	Public.
Strong City	762	Shallow wells	Public.
Syracuse	1,126	Deep wells	Public.
Topeka	43,684	Shallow wells	Public.
Turon	572	Shallow wells	Public.
Udall	330	Shallow wells	Public.
Valley Falls	1,129	Springs	Public.
WaKeeney	883	Deep wells	Public.
Wakefield	514	Shallow wells	Public.
Waldo	300	Shallow wells	Public.
Wamego	1,714	Shallow wells	Public.
Washington	1,547	Impounded	Public.
Waterville	704	Shallow wells	Public.
Waverly	751	Shallow wells	Public.
Weir City	2,289	Deep wells	Public.
Wellington	7,034	Shallow wells	Public.
Westmoreland	484	Shallow wells	Public.
Wichita	52,450	Shallow wells	Private.
Wilson	981	Shallow wells	Private.
Winfield	6,700	Walnut river	Public.
Yates Center	2,024	Impounded	Private.

There are 198* cities in Kansas with water supplies for fire and domestic purposes. Two of these cities are supplied from other municipalities—Rosedale from Kansas City, Mo., and Gas City from Iola—leaving 196 waterworks plants in the state. The total population of the cities supplied with water is 664,022, or more than one-third of the total population of the state. Of the 196 plants, 182, or 93 per cent, are owned by the municipalities; 16, or a little more than 8 per cent, are owned by private companies. The population supplied by private companies is 157,863, or a little more than 24 per cent of the total population of the cities supplied with water, showing that some of the largest cities of the state are not maintaining municipal waterworks plants.

There are 40 surface supplies in the state, or 21.2 per cent of the total number of plants. These supply a population of 288,503, or 43 per cent of the total population supplied by waterworks plants, as many of the largest cities are supplied with surface water.

* There have been additional waterworks plants constructed since this was written. in 1914, at the following places: Natoma, Burden.

There are 156 plants utilizing ground water supplies, or 78.8 per cent of the total number of plants, supplying 375,519 people, 57 per cent of the population tributary to waterworks plants.

There are 32 cities supplied with water from the larger streams and rivers. The population of these cities is 272,990, or 73 per cent of the total population supplied with surface water and 41 per cent of the total population tributary to waterworks plants in the state.

The 10 cities supplied with water from the small dry-weather streams have a population of 15,513, or 5.5 per cent of the population supplied with surface water and 2.3 per cent of the total population tributary to waterworks plants. The number supplied from smaller streams and impounded reservoirs is extremely small compared with many eastern states. This fact is not surprising, considering the flat topography of the state, with its lack of suitable reservoir sites. There are no lakes or natural ponds used as sources of water supply.

There are 29 cities supplied from deep wells. These cities have a population of 64,163, or 17 per cent of the population supplied with ground water and 9.6 per cent of the total population of the state tributary to waterworks plants.

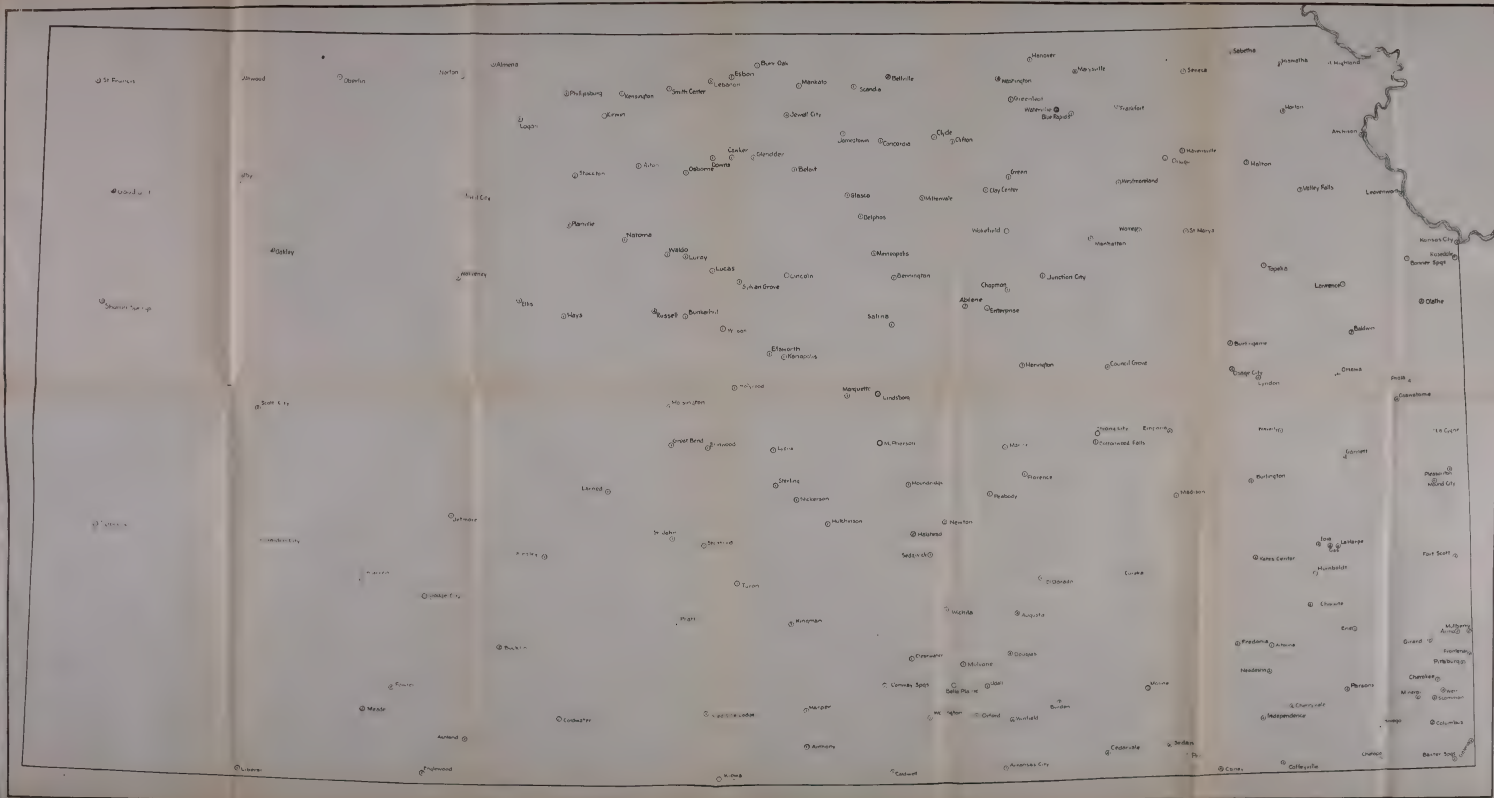
The number of plants utilizing shallow wells is 111, 56 per cent of the total number, supplying a population of 290,335, or 77.5 per cent of the total supplied with ground water and 44 per cent of the total population of the state tributary to waterworks plants.

The number using springs as a source of supply is 10, or a little more than 5 per cent of the total number of plants, supplying a population of 21,021, or 5.6 per cent of the total population supplied with ground water and 3.2 per cent of the total population of the state tributary to waterworks plants.

Plate I shows the cities of the state with waterworks plants, the numbers in the circles denoting what their souce of supply is. Plate II and III show, respectively, the ground water supplies and the surface water supplies, showing the distribution.

WATERWORKS PLANTS OF KANSAS

LEGEND
- ① SHALLOW WELLS
- ② DEEP WELLS
- ③ SPRINGS
- ④ SURFACE WATER



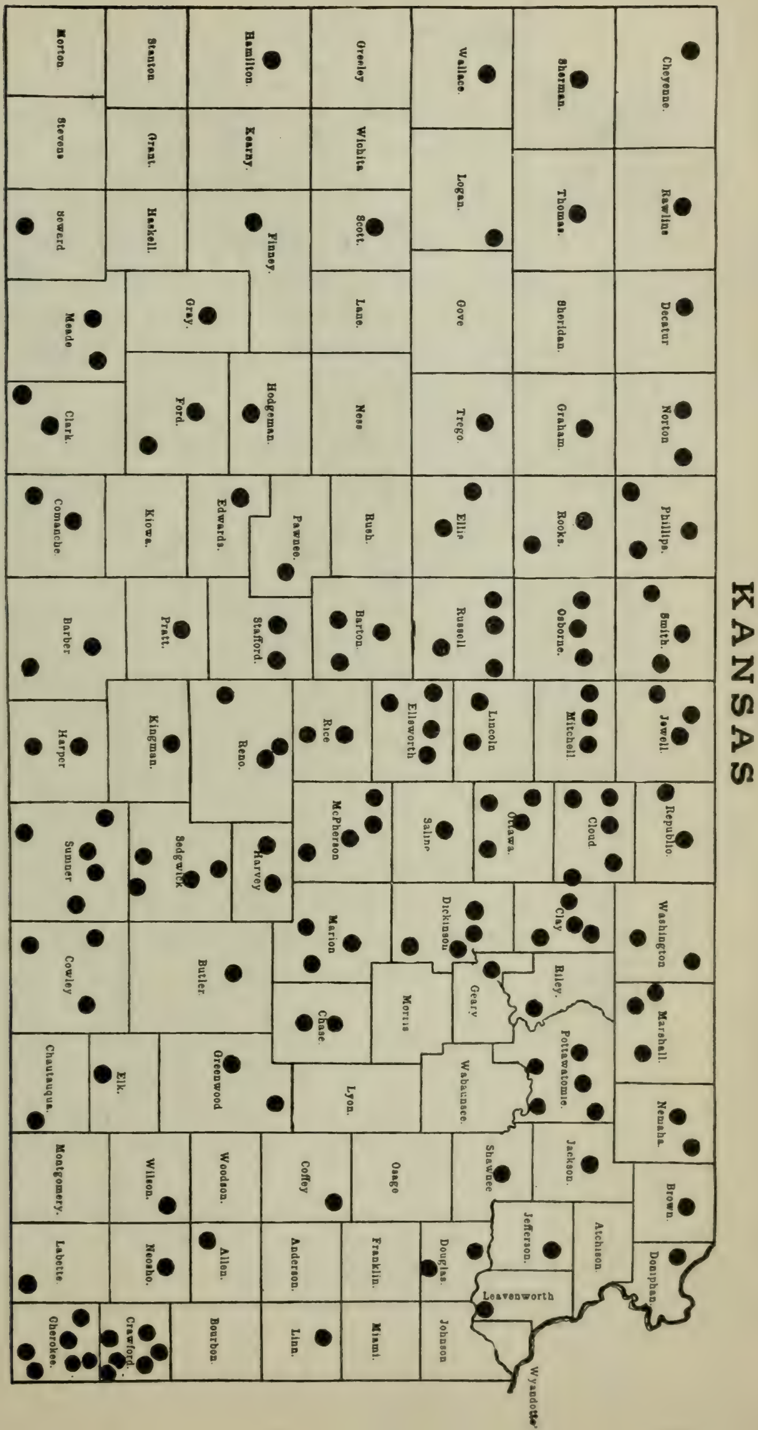


PLATE II. Distribution of ground water supplies.

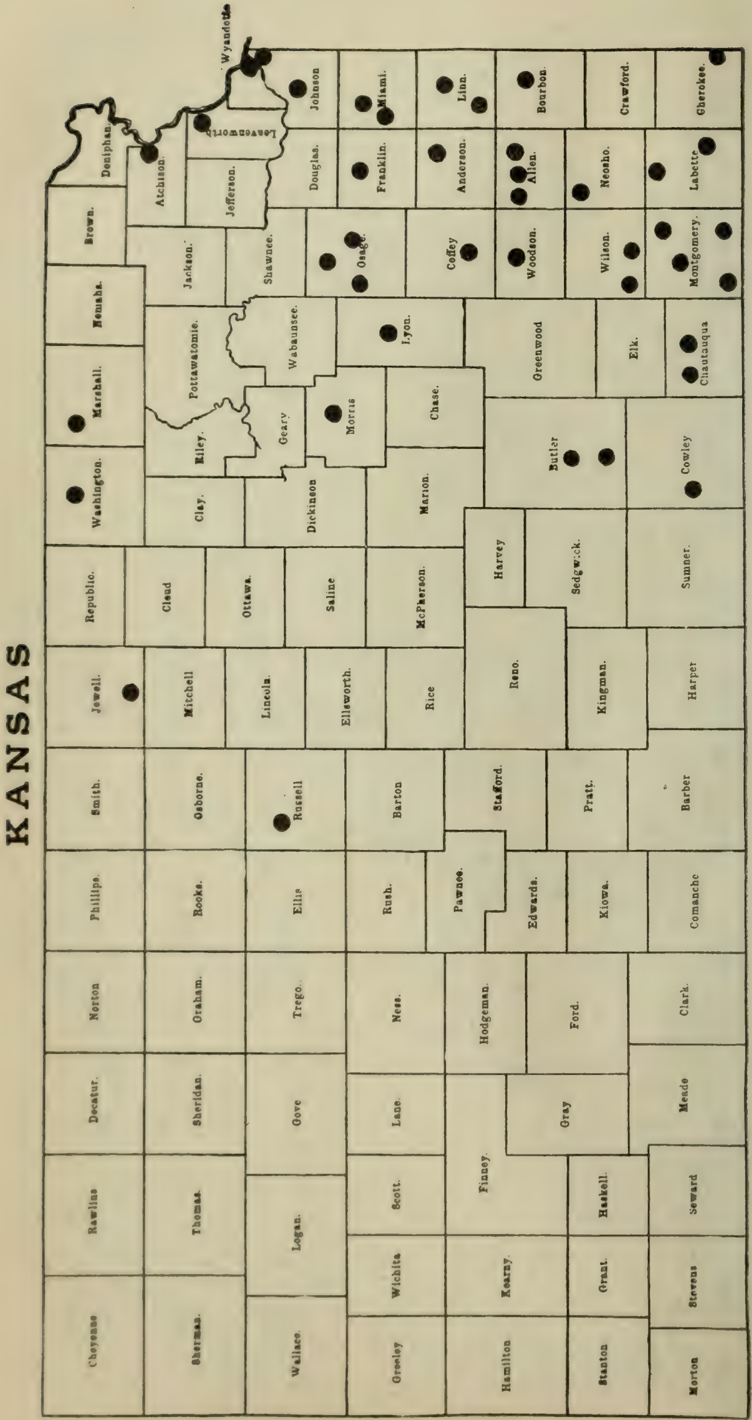


PLATE III. Distribution of surface water supplies.

CHAPTER II.

GROUND WATER.

A varying amount of the rain falling on the surface of the earth is absorbed by the soil on which it falls, and it percolates downward until some impervious stratum or some stratum which is more porous than that in which it is already traveling is encountered. Then it tends to follow a more or less horizontal slope toward some river, stream or the sea. The underground flow is affected by the same laws that affect the surface flow, modified, however, by certain conditions of friction, capillary attraction and geological formations. The quantity of the flow of underground water is dependent upon the character and amount of the area upon which the rain falls, the porosity and amount of the pervious strata through which it is flowing, the head under which it flows, etc.

On account of the varying conditions regulating underground flow, ground water may be divided into three classes: First, that obtained from alluvial deposits; second, drift; and third, stratified rock. The water secured from alluvial deposits is probably the most commonly used for city supplies, where ground water is used, and is that which is derived from the silt and debris found deposited in pockets along most river and stream beds. The amount of water which may be secured from that particular source varies as the size of the catchment area, character of the water-bearing strata, its geological formation, etc., vary. For instance, some rivers in Kansas have large deposits of extremely coarse and porous soil along their valleys, such as the Arkansas river, with extensive underflows, from which the cities of Wichita, Hutchinson, Dodge City and others secure their supplies. From this material the water may be recovered with comparative ease, simply by driving small shallow wells into the water-bearing strata in almost any location in the river valley.

An unusual condition has been created along the Arkansas and other streams in the western part of the state to cause this pervious layer. These streams, flowing originally over a practically impervious layer, have covered up their bed planes by erosion of materials further up stream and by the distribution of sand and gravel, filling in with this extremely pervious material to great depths, from which inexhaustible quantities of

water may be secured. In most of the localities along the Arkansas river an underflow is found at a depth of a few feet; separated from this by a thin layer of clay may be found what is known as the second underflow, at a depth of from forty to fifty feet; and still deeper, and likewise separated by a layer of clay from the second underflow, may be found the third underflow. This condition does not prevail all along the river, but the third underflow has been tapped for the city supply at Dodge City and by wells put down under private enterprise at Kinsley, Garden City and other places. In the upper reaches of the Arkansas river in Kansas a curious fact about the several underflows is that the first underflow furnishes very hard, highly mineralized water; the second, while much more desirable than the first, is still rather hard; but the third underflow furnishes a relatively soft water for Kansas, and most of the cities along the river have attempted to find the third underflow in order to get the benefit of the better water. An impression seems to prevail, however, that the third underflow does not always remain soft; that is, it is believed that by pumping the supply for a few years the water becomes very much harder and approaches in quality the second and first underflows. On account of the fact, however, that practically all of the wells put down are cased with galvanized-iron casing, which is very subject to corrosion, it is believed that this alleged increase of hardness may be caused by a leakage from the shallower underflows, which were cased through in order to reach the soft water, and that if the casing were of indestructible material the supply would remain practically the same in point of hardness.

As the lower end of the valley is reached, a bed of hard shale is encountered—at Hutchinson at a depth of 75 or 80 feet and at Wichita at a depth of from 35 to 40 feet. The three underflows in this neighborhood are not separated, but still large quantities of water are available. At Arkansas City the width of the underground water is narrowed down considerably by the protruding rock ledge separating the Arkansas and Walnut rivers on one side, and the outcropping of the shale forming the original bed on the other, so that the city supply is developed here very close to the bank of the stream.

Along the Kansas river and several other streams large quantities of water are available at most places, but care must

be used in selecting a site for the wells. On account of the fact that deposits of water-bearing material are not as regular on the serrated floors or bed planes of the impervious material, and on account of the fact also that finer materials are mixed in with the water-bearing strata, a much slower rate of progress for water through the material is caused. Lawrence, Topeka, Junction City, Manhattan and Salina are some of the larger cities using water of this character. At Lawrence a large bed of sand and gravel found at a depth of 20 to 30 feet below the surface of the ground and varying in thickness from 20 to 30 feet has been utilized for securing water for the city supply. This pervious layer seems to rest upon an impervious layer of shale and rock, at a depth at the waterworks plant in Lawrence of approximately 50 feet below the surface. On account of the extreme unevenness of the impervious rock layer forming the bed of the river, it is probably true that there is no well-defined underflow from the headwaters to the mouth, but nevertheless there are many long pools in which there is a flow in a general direction toward the river and tending to parallel the direction of the valley.

Along some of the other streams of the state, while the original beds have been filled in by debris, such large quantities of clay and other fine-grained materials have been deposited in proportion to the sand and gravel that the rate at which the water may be secured is very slow. For instance, extensive tests have failed to show an adequate quantity of water available in the valley of the Verdigris river at Independence and Coffeyville to supply these cities. The same is true of the Neosho valley at Chanute, Iola and Emporia. About 1908 an attempt was made to develop a ground water supply for the city of Winfield in the valley of the Walnut river, and a plant was built to utilize the river underflow. In a short time, however, it was apparent that from the existing works a sufficient quantity of water could not be developed, and, on account of the expense of constructing large underground works for the collection of the water, it was deemed advisable to use water directly from the river and treat it. The same experience was passed through in Augusta. At El Dorado, where the east and west branches of the Walnut unite to form the Walnut river proper, extensive underground tunnels or infiltration galleries, approximately 1200 feet in length, have been constructed in

the narrow strip of land between the two streams for securing water for the city. To assist in holding the ground water level up, or, in other words, to prevent the seepage of ground water into the stream, a dam was constructed just below the junction of the two branches, so that more water could be secured by means of the head thus formed on the underground water, through the infiltration gallery. At the present time it seems that the limit in the amount of water which may be secured with a reasonable expenditure has been reached, and the city is contemplating the use of treated river water for at least a part of the supply, should the consumption increase to any great extent. Attempts have also been made without success to find ground water at Fredonia on the Fall river, and at many other cities in the middle and southeastern parts of the state.

Occasionally conditions are found wherein old river beds have been completely covered over, due to certain geological phenomena, and when conditions like these are found supplies may be developed from the porous material which was deposited by the ancient streams in their beds. The city supplies of Newton, Halstead and McPherson have been developed in the bed of an ancient stream, which it is believed formerly connected the Smoky Hill with the Arkansas. Although no surface indications of this fact can be seen, extensive borings made in that vicinity are responsible for this theory. At any rate, large quantities of relatively soft water have been developed over an area comparatively narrow east and west but long north and south, in that neighborhood.

In securing water from wells in river valleys, the common belief among laymen is that a certain amount of the water is collected normally from the sand and gravel deposits that has not yet reached the river, and also that large quantities of water pass from the river through the sand and gravel to the wells. Such seems to be the general idea of the source of supply at Lawrence, Topeka, Manhattan, Salina and many other places. As a matter of fact, however, it is very seldom true that water is secured in the latter manner. This belief is caused probably from the fact that usually during times of flood wells close to streams seem to contain more water and yield it more readily than in times of dry weather, and the conclusion that this excess of water comes from the stream is but natural. Most of

the streams, however, during times of flood carry large quantities of finely divided sediment. When water carrying sediment attempts to pass through a layer of porous material the flow is broken up and the rate of travel is lowered. Since the carrying of sediment is dependent upon the rate of flow and the size and specific gravity of the sediment being carried, it will

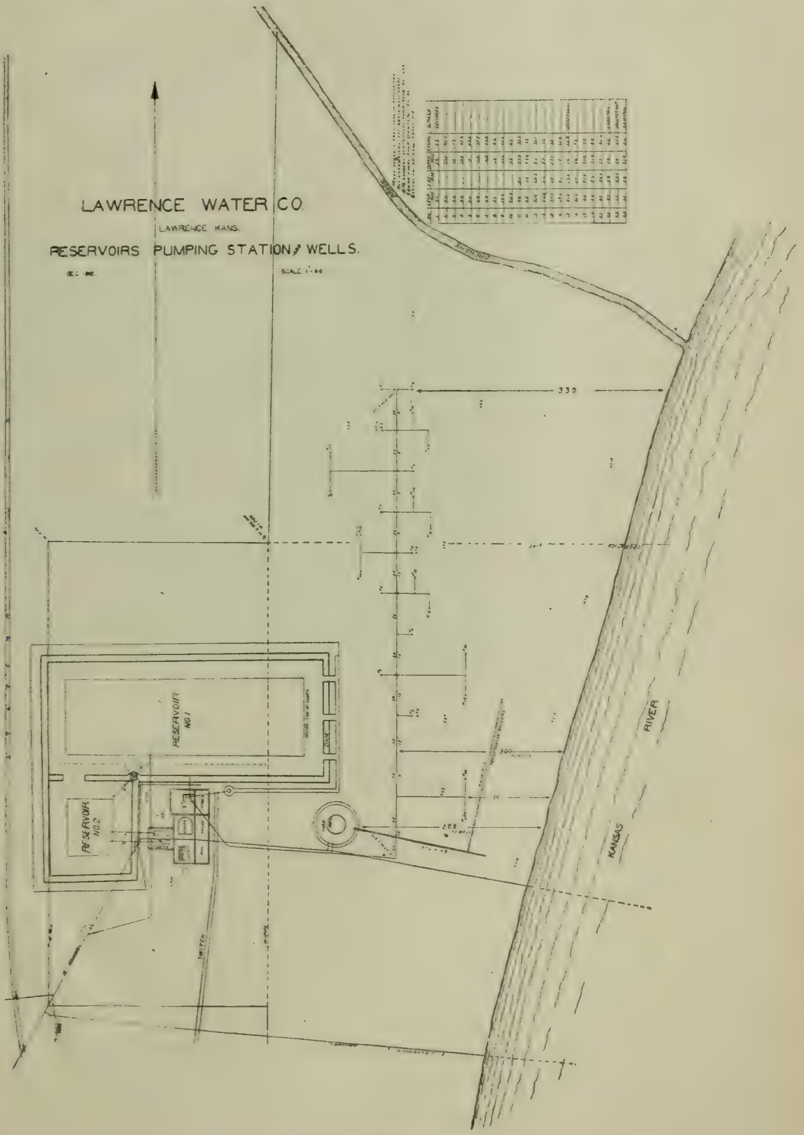
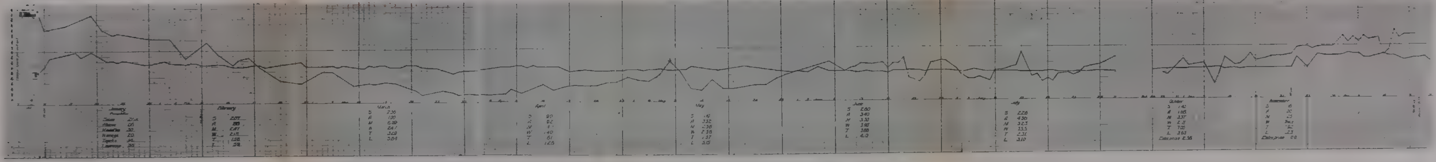


PLATE IV.

readily be seen that this finely divided material will be deposited, or possibly be strained out of the water. In a very short time the porous material will be completely filled up—that is, clogged by it, so that very little, if any, water may pass through it. Since the ground water flowing along the banks of streams tends to flow into the river and appear in seepage along the river banks, a slight rise of the water in the river would furnish a pressure to hold back this ground water from such seepage; consequently the rise of the ground water would be expected in any well drilled on the river bank at times of flood.

An interesting proof of this fact has been developed at Lawrence. The city supply is secured from a layer of sand and gravel along the west bank of the Kansas river, as shown in the accompanying illustration (Plate IV). From time to time during the years 1909, 1910 and 1911, sufficient analyses of the Kaw river water and the Lawrence city supply had been made, so that the chlorine content of the ground water was known to be very nearly constant, while that of the river water varied between wide limits. On account of the fact that a sufficient supply of water from the ground could not be secured, due to inefficient methods instituted by the water company, it had been the custom to reinforce the supply with water directly from the river. Therefore, if it were known when the river water was being used, changes in the chlorine content of the two waters could be accounted for. A study of the curves (Plate V) accompanying show the results of the analyses for chlorine in the two waters, and a study of the table showing the periods during which the river water was added to the city supply, will convince one that the river water only reached the supply through a pipe connecting it directly, and not through the wells.

Further proofs of this general statement may be found in the water supplies of two or three of our cities in the southeastern part of the state. They attempted a few years ago to develop a supply of river water, purifying it by a filter consisting of an underground tunnel connecting the suction well directly with the river water. These tunnels were filled with gravel, sand, "chats" and other porous material, with the hope that the river water filtering through would be sufficiently clarified to be suitable for domestic use. The experiences of all



of these cities were that shortly after the river water was turned into the so-called filters, the filters became so clogged with sediment that it was impossible to get a sufficient supply through them, and it was necessary to clean them out with dynamite in order to get water. This same condition may be shown in the operation of water filters. In filtering the turbid water of our western streams it is the practice to pass water through a bed of sand and gravel 35 or 40 inches thick, collecting it underneath through a system of strainers. The water is passed through the sand to a clear well at the rate of about two gallons per minute per square foot of filtering surface. The silt and mud thus filtered out of the water collects on the top of the filter bed, and it is necessary each day, in order to keep water going through the filters, to pump a reverse current of water back from the clear well through the strainer system and up through the sand, in order to wash out the accumulated mud of the day's run.

Certain conditions will permit water to travel from a stream into a well. For instance, if there is a direct connection of a fissure through limestone, the water in the river will affect the level of the water in the well. Also, in some of our streams in western Kansas the character of the soil around them is so very coarse, consisting principally of sand and gravel, that the water in the stream will entirely disappear, dropping down into the underflow. In some of these cases, where wells are close to the stream, a direct connection might occur. As a general rule, however, this is not probable.

Another very common source of ground water supply in Kansas is that secured from deposits of glacial drift. In other words, that secured from pockets of water-bearing material which were deposited in the depressions of the ground surface in the glacial age, brought down by the huge glaciers from the north. The glacial area of Kansas is bounded roughly by the Blue river on the west and the Kansas river on the south, although in some cases it extends beyond these boundaries, evidences occasionally being discovered here and there of this fact. The glacial debris rests upon a floor of stratified rock, consisting principally of shale and limestone. When the ice of the glaciers melted, a great deal of water was produced and many temporary lakes and river channels were formed which

have long since gone out of existence. The finer grained and lighter materials were carried about and deposited promiscuously, the bed planes of such materials conforming more or less with the surface of the ground. Many of the old river channels were entirely filled with these glacial deposits, and subsequent erosion has produced a new drainage system.* All of these deposits contain water to a greater or less extent, and in some places have been utilized for city supplies by cities located near them. Very often, however, the supply is more or less limited, and on account of the promiscuous distribution of material and the change in surface contours, the deposits sometimes are hard to locate.

The city of Holton formerly took water from what was considered a glacial deposit, but on account of the extreme thinness of the strata the supply proved inadequate. The city of Valley Falls at present is securing water from a spring which has a catchment area of sand and gravel probably deposited during the Glacial Age. Several other small cities in the district before mentioned are also taking water from wells in similar deposits.

A third source of supply which is used extensively in this state is that known as the Tertiary deposits, which consist of a light or porous soil, composed principally of sand, silt and gravel, with an impervious layer underlying the extensive deposits over the greater part of the western half of the state, forming a natural barrier to further percolation downward. These Tertiary deposits carry an inexhaustible quantity of water and are more or less uniform in distribution and character. The cities of Goodland, Colby, Wa Keeney, Scott City, Liberal, and many others in that district, in which the rainfall is very light, find abundant supplies of water at a depth of between 100 and 200 feet by merely drilling a well in almost any location desired. The water seems to be of excellent quality and has been extensively developed also for use in irrigation. Many of the rivers in this district have carried and deposited alluvial material and debris of the Tertiary Period until the bed planes are filled and the streams are flowing through their own deposits far above their original position. In a great many cases the flow of the streams is reduced at times to very small amounts, or to no flow at all, but it seems that uniformly

* Special report on well water by E. Haworth, 1913.

large quantities of water may be secured in the valleys. The famous underflow of the Arkansas river, which supplies water to all of the cities along that stream, is an example. Many underflows of streams in that neighborhood are also similar. Near the Arkansas river, in districts in which there are no well-defined streams, except in times of flood, this water may be found. These immense bodies of water following the rivers, while they may be classed either as water from Tertiary deposits or water from the river alluvia, are usually classed by themselves. The cities of Pratt, Kingman and Clearwater have developed supplies along the Ninnescah river, as also have other cities along the Chikaskia, the Cimarron and Rattlesnake creek, although it seems that wells in any location desired in the whole western part of the state, whether along a stream or on the upland, will yield large quantities of water.

Still another source of city supply is that secured from or beneath stratified rocks. The most highly developed of these are the supplies in the southeastern part of the state. For instance, Pittsburg, Columbus, Girard and several smaller cities have developed supplies from what is known as the Mississippi limestone. This water, it is generally supposed, comes from the rain which falls where the stone outcrops in Missouri. It is a fact that the limestone is at the surface in the Ozarks and that it dips to the west toward the Rocky Mountains. Near the outcropping the water in it is found to be of most excellent quality. The further west one goes, however, the more the water becomes impregnated with certain undesirable constituents. For instance, the cities in Kansas utilizing this source are troubled with hydrogen sulphide gas which the water carries, and this gas must be removed by aëration and sedimentation before the water is pumped into the mains. Several other small supplies have been developed from similar deposits of stratified rock at a lesser depth; for instance, the Cherokee shales which overlay the Mississippi limestone and vary in depth from 400 to 500 feet. This strata has been tapped at several points, notably at West Mineral, Scammon and Cherokee. The water in the sandstone, while seemingly not present in such inexhaustible quantities as in some other stratified rocks, is more desirable on account of the fact that it is less highly mineralized and does not contain hydrogen sulphide gas.

The Dakotá sandstone. which is found in widely separated areas in western Kansas at a depth of 75 to 200 feet, is generally used in some of the other states to the north, where it is more available for furnishing water. Syracuse, Larned, Belleville and Minneapolis are some of the cities utilizing it in this state. There are many other deposits of stratified rock in Kansas which furnish water to a greater or less extent, but few of them are used for city supplies. For an extended discussion of the geological formations of Kansas and the water-bearing qualities of each, the reader is referred to Bulletin No. 1 of the University Geological Survey of Kansas, by E. Haworth, State Geologist.

CHAPTER III.
RECOVERY OF GROUND WATER.

Before describing the various methods of obtaining water from the ground for municipal supplies, it might be well to explain some of the fundamental laws governing the action of ground water. In the first place, no more water can be taken from the ground than enters it, and all ground water originates in the form of rain falling upon some catchment area. A part of the rain, after falling on a catchment area, percolates downward under the action of gravity until an impervious stratum is reached or until the point of saturation of the pervious stratum is encountered. The surface of the water forms what is known as the water table or ground-water level. The amount of water percolating into the ground from a catchment area is dependent then upon the rainfall, upon the area, the size of the area and the absorption value of the soil, which depends not only upon the relative porosity of the soil but upon the character of vegetation and the topography. A surface covered with dense vegetation holds much more water to be evaporated by the sun's rays than that without. Again, in certain soil, capillary action, which facilitates evaporation, is important. Naturally, the steep slope of some catchment areas permit a quick run-off, and the amount of percolation is therefore lessened. The amount of water available in pervious strata depends upon the rate of flow of the water through the strata and the storage capacity. The rate of flow is governed by the friction the grains of sand offer to the water flow. It, therefore, is dependent upon the size of the grains and compactness of the material and upon the hydraulic gradient, or the rate of fall from a higher to a lower level. The storage capacity is governed by the size of the strata, the depth and the porosity. The porosity varies in rock from less than 1 per cent in some of the finer-grained granite to more than 30 per cent in some of the looser-grained sandstone. In sand the porosity varies from 30 to 40 per cent, depending upon the various sizes of the grains. In sand and gravel mixed it varies from 25 per cent to 40 per cent. If we could imagine a soil made of perfect spheres, the porosity would be about 26 per cent, but the uneven sizes of the grains of most material allow greater void spaces in some cases and less in others. All of these foregoing

conditions may be investigated and absolutely determined, so that, in a large measure, the failure of underground water supplies, which is so common, could be predicted if careful and thorough studies were made before the supply was developed. Water tends to seek its own level under the action of gravity under ground as well as on the surface, but the friction or resistance offered to the flow of water retards this action. If, however, for any reason, the underground water level is lowered at any point the water table immediately tends to level itself, causing flow. If a well is drilled into a pervious stratum of a particularly uniform porosity, the water will stand in the well ordinarily at or near the level of the water in the ground. If the water in the ground is under some head, however, the water in the well will rise in proportion to that head. When the water in the well is lowered below the water table by pumping, the water in the ground tends to adjust itself, and an inverted cone-shaped figure is formed, the inclination of whose sides is dependent upon the rate of flow or the friction in the sand. Formulæ are developed for the velocity of flow and the amount of water that can be taken from any particular pervious stratum by a study of these various conditions. The base of the cone is known as the circle of influence, with the apex at the level of the water in the well. In case the water table before pumping is level, the circle of influence will be practically a true circle, but if the water is flowing through the sand it will tend to be distorted. If the ground water is present as in a reservoir, and the well is pumped until the pumping exceeds the percolation on the surface, the circle of influence will enlarge until the whole area of the reservoir is included, and the supply of water will in time be completely exhausted. If, however, the water is flowing through the stratum in a body, the level of the water in the well will only be lowered until the circle has enlarged enough to include an area into which the flow exceeds the pumpage. In case of artesian wells—that is, wells which tap a pervious stratum with impervious strata above and below to cause pressure or head on the water—the flow of the water into the well is not accompanied by a change of the level of the water surface, but the water pressures will change in a form similar to the water table just discussed. In case a gang of wells is constructed, these circles of influence are apt to intersect each other, and then the wells are said to

interfere; in other words, the yield of each well will be correspondingly lowered, since the area from which it may draw upon is limited by the other wells. In developing ground water there is a certain amount of resistance to flow which has not yet been discussed—the friction of entrance into the well casing, and, in the case of very deep wells, the friction of the well itself. The friction of entrance is most important, however, and problems of this sort have been productive of many styles of casings for small driven, drilled and bored wells and for the lining of large dug wells.

The works for the collection of ground water are divided into the following types:

1. Large open wells.
2. Tubular or drilled wells.
3. Deep and artesian wells.
4. Infiltration galleries.
5. Push wells.
6. Cribs or works for the collection of spring water.

The simplest form for shallow wells would seem to consist of large open wells, especially where the pumping is constant. Wells of this type have several advantages: First, the advantage of storage where the pumping is intermittent; in other words, the advantage of allowing a certain amount of water to flow into and be stored in the large well, which may be pumped out at a uniform rate in relatively short periods of time. Second, the slower entrance velocity of the water, since the water entering at any given rate will have a larger area to enter from, the velocity will not need to be nearly so great in the case of a large open well as in the case of a small drilled well; therefore, the problem of combating fine sand or silt in the well is greatly lessened. Third, large open wells with a slow entrance velocity may be so arranged that the fine material can settle after it reaches the well before the water gets to the pump suction. Fourth, an advantage over a gang of small wells is in the avoidance of the use of long suction lines. This is only true in cases where plenty of water is available. Fifth, when the water table is low, or will be lowered by pumping, a more economical form of pump may be used by placing it inside of the well, at a lower level. The main disadvantage of the large open wells lies in the increase of cost with the increase of depth, over the cost of driven wells, especially where a large number is necessary, and also from the

fact that the yield of a large well is in no way proportionate to the increase of size over the small well. In case more than one or two large wells must be constructed, it will often be advantageous to construct a pump pit alongside a gang of wells and to lower the pump rather than to construct more large wells. This depends, however, upon the character of the material through which the wells must be sunk. The large open wells are usually constructed by excavating for a short distance, setting a shoe of wood or metal with a metal cutting edge at the outside circumference of the well, and building up the wall of brick or concrete, excavating from the inside, allowing the wall to settle by its own weight. In some cases the walls are weighted in order to enforce them down faster. The entrance of water into these large wells is provided for by laying that part of the wall which will be in the water-bearing stratum without mortar—in other words, a dry wall—or by leaving other special openings in the bottom section. As a rule, then, dug wells are to be constructed in preference to tubular wells in locations where comparatively shallow water may be obtained, excavation not difficult, and the pumping intermittent. Large dug wells form the majority of installations for securing shallow well water in Kansas, except, possibly, those shallow wells tapping the Arkansas underflow. One of the deepest dug wells in Kansas is the one which had been used by the city of Belleville until 1912, which was discarded for driven wells. This well was fifteen feet in diameter and about 150 feet in depth, tapping the Dakota sandstone. Some of the shallowest wells are only as deep as 15 or 20 feet, as, for instance, the shallow well supplying the city of Larned from the Arkansas underflow, and also Garden City from the same stratum. Occasionally very narrow dug wells are constructed, as, for instance, the deep well at Bucklin, which has a diameter of 6 feet to a depth of 104 feet. In the bottom of this a 16-inch hole is drilled to the depth of 125 feet. Others in that neighborhood have practically the same construction.

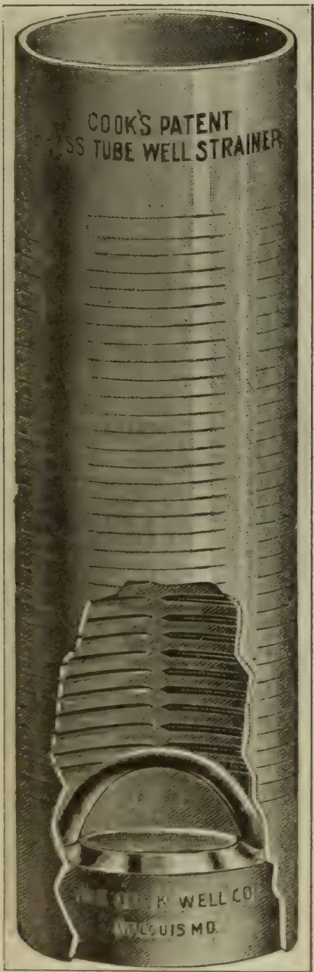
Tubular wells are driven, bored or drilled. Driven wells are those small wells in which there is a sand point with a pointed end and a perforated section. The perforation is sometimes covered with a brass screen. The casing is driven into the water-bearing stratum. These wells are suitable where the water is thinly distributed, and generally are not suited for

PLATE VI.
BULLETIN No. 5—Ground Water Supplies of Kansas.
Engineering Experiment Station, University of Kansas.
Courtesy of Cook Well Co.

large supplies. However, on account of their cheapness, the ease with which they may be constructed and the ease with which the casings may be pulled out and used again, they are commonly used for prospecting for water supplies. A common form of wells for developing large supplies are those wherein the casing is sunk by driving or drilling a casing and washing out the loosened material with a water or steam jet inside. One advantage of this form of construction is that quite often fine material is also drawn in through the perforations and washed out, leaving a deposit of coarse-grained material on the outside of the casing. These wells are known as driven or drilled tubular wells, also sometimes as open-end wells. Strainers of various types to overcome corrosion and clogging by fine material have been developed, and also various methods of preparing the soil adjacent to the strainers have been used.

One of the most common forms of strainer is simply a piece of galvanized iron or other metal, perforated with small holes in case the water-bearing material is coarse. Sometimes, in order to keep out fine sand, the perforations are covered with a brass screen. Sometimes a solid tube is sunk through the porous soil, a special strainer inserted of suitable length, and the top then withdrawn to the top of the strainer. An ordinarily used special form of strainer is what is known as the Cook strainer. This is made of brass tubing and provided with narrow circumferential slots which flare toward the inside of the tube, an arrangement intended to prevent clogging. The Cook strainer is illustrated in Plate VI.

Another ingenious form is what is known as the Johnson strainer, in which a brass strainer with elliptical perforations is overlaid on the outside by a brass screen with circumferential slots continuous all around the casing. Another form which is manufactured in Kansas is constructed of cement. A special form for the cement has been made of metal with lugs spaced at intervals which are wider on the inside than on the outside, leaving a section of concrete with narrow slots opening vertically on the outside and wide on the inside. This casing is illustrated in Plate VII, and has been used at many



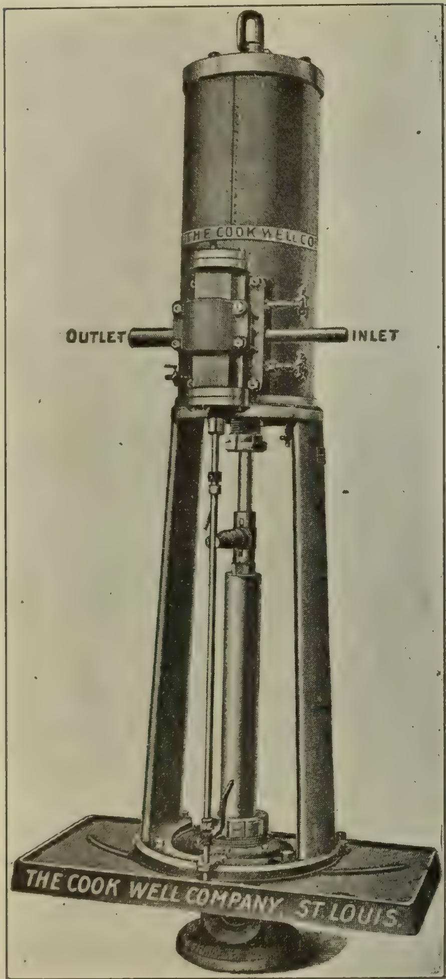


PLATE VIa. PLATE VIb.

Courtesy of Cook Well Co.

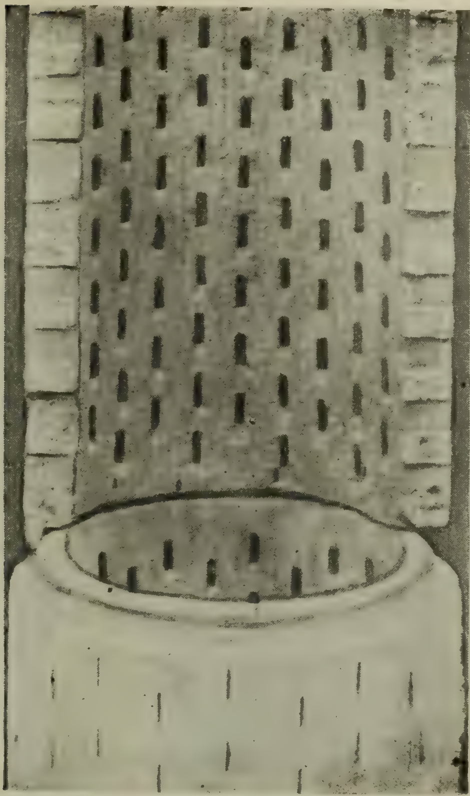


PLATE VII.

Courtesy of Smythe Storage Co.

of the smaller waterworks plants over the state where the wells are not too deep. One advantage of this is in its permanence. The Layne & Bowler Company, of Houston, Tex., have devised a system of well construction illustrated in Plates VIII and IX. A large casing of boiler steel is first sunk to an impervious stratum, then a smaller casing, known as the Lane shutter screen, with a cone-shaped enlargement on the bottom with slotted horizontal openings, is sunk on the inside. The annular space is then filled with coarse gravel and the outside casing pulled up to the top of the screen. A centrifugal pump of special design is placed in the cone-shaped section for forcing the water to the top. All of these methods have been developed in attempting to avoid the difficulty of clogging by fine sand and to reduce entrance friction. The

ordinary perforated casing is used in a great many plants This style has been adopted by the plants at Wichita, Hutchinson and Lawrence, as well as many others. The Cook and Johnson strainers also have been commonly used. The Layne & Bowler well system has been installed at Newton, Arkansas City, Wellington and Manhattan.

In general, it may be said that that casing is the best adapted to any particular location which has openings of such a total area and shape as offer the least resistance to the inflow of the water and which will at the same time hold back fine material. It should also be constructed of material which does not easily corrode. No strainer can be recommended for every case, each supply being a special problem in itself.

Bored wells are usually those deep wells in which strata of rock are encountered and passed through; however, occasionally wells are bored in shale or in sandstone or in still softer materials. Casings are usually sunk to a great depth in such wells, on account of the high resistance of the uncased walls of the well to the upward flow of water. It is usually customary to sink a casing a little larger than the desired size down as far as possible, then to start a smaller casing inside of that and carry it down another distance, and even sometimes a third, almost to the bottom of the well. The deep wells of southeastern Kansas, including those at Pittsburg, Columbus, Girard and others, are usually constructed in some such manner. The water under its natural head rises up a considerable distance in the well, but it is necessary to pump it in order to get it to the surface.

When large quantities of water are needed from relatively thin but widely spread areas of porous material, it is sometimes feasible to construct infiltration gallaries at right angles to the direction of the flow of the water through the material. The hydraulics of these galleries is very similar to the hydraulics of wells. An infiltration gallery several thousand feet in length across the valley of the North Canadian river, to intercept its underflow, has been proposed for Oklahoma City. These are best suited where the porous material is at a shallow depth and where excavation is not difficult, and are constructed of brick, concrete, stone or vitrified tile, with suitable openings left for the entrance of the water. Infiltration galleries are in use at El Dorado, Lawrence, Smith Center and Moline.

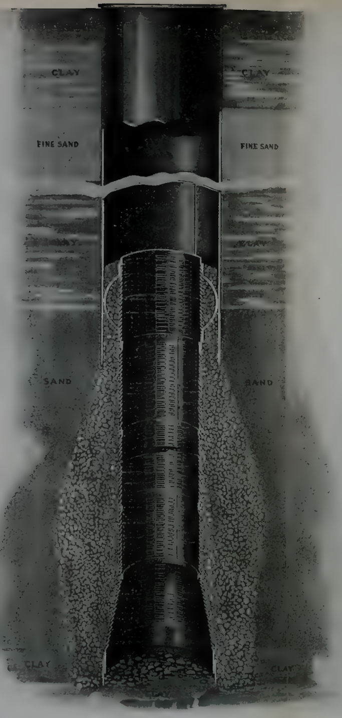


PLATE VIII.
BULLETIN No 5—Ground Water Supplies of Kansas
Engineering Experiment Station, University of Kansas
Courtesy of Layne & Bowler, Houston, Tex.

PLATE IX
BULLETIN No 5—Ground Water Supplies of Kansas
Engineering Experiment Station, University of Kansas
Courtesy of Layne & Bowler, Houston, Tex

Courtesy of Layne & Bowler, Houston, Tex.

WELL SYSTEM AND PUMPING PLANT OF MUNICIPAL WATERWORKS, NEWTON, KAN.

Works for the collection of spring water usually consist of wells into the previous stratum from which the water springs, for the purpose of allowing the spring water to flow into them and be retained for pumping; or infiltration galleries may be laid along the bottom of the porous stratum from which the water springs. At Burden a large concrete reservoir has been built around some springs, holding several day's flow of water, from which water is pumped to the city. At Kingman a wood pipe with branches of sand points driven horizontally into the water-bearing stratum has been used, emptying at the lower side of the porous stratum. At Herington concrete cribs are being constructed, which discharge through a flow line into a large well. This flow line is being constructed through a part of the porous stratum, and open joints are being left through this material for the further infiltration of water.

CHAPTER IV.

PUMPS.

Water is secured from wells either by siphonage, displacement pumps, impulse pumps or jet pumps, depending upon the conditions of location and operation. Where water is available in a gang of tubular wells, with its level fairly close to the surface of the ground, these wells may be connected through a siphon pipe to a large receiving well, the siphon terminating below the level of the water in the tubular wells. The air may be pumped from the siphon line by vertical vacuum pumps, and the water will flow across into the receiving well, where it may be pumped into the distribution system by high-service pumps. This is the system used at Wichita for securing water from forty-eight 8-inch wells ranging in depth from 30 to 40 feet, where the water table is within 12 or 15 feet of the ground surface. The wells are divided between two siphon lines, both discharging into the large receiving well. Suitable air release chambers are placed on the siphon line, and by comparatively small air pumps the air pumped out of the line, and an average of from 4,000,000 to 5,000,000 gallons of water is secured there from one well pumped in this manner, under test, although the wells do not furnish that amount of water ordinarily on account of interference. Displacement pumps of piston or plunger types are frequently used for low-service work, especially where water is available in large quantities within the suction limit of such pumps. Frequently the use of this type of pump may be very economical, in that only one set of pumps is necessary. For instance, at the city of Hutchinson the pumps furnishing high pressure to the city secure water from the ground by direct suction. The same is true of Garden City and Dodge City and very many of the smaller plants. At Hutchinson, however, two auxilliary pumping plants with several wells have been constructed in different parts of the city, which reinforce the pressure from the main pumping plant, done both for the purpose of obviating the necessity for further extension to the collection system in the main plant and to preclude the necessity for installing some larger mains, it having been decided that pressure on the outskirts of the city could be maintained more easily and reasonably by "booster" pumps than by expending large sums for extensions to the distribution system. Electrically driven centrifugal pumps were installed

and the expense of attendance minimized. Very often, where water is at a very low level in the ground, displacement pumps are employed with the working parts at or near the surface of the ground, and the pump barrel placed down on the well within suction distance of the water surface. A great many of these deep-well pumps are used in Kansas.

Impulse pumps are used either where the water is at a low level in the ground, and it is necessary to pump it twice, or where the ground water is of such character that it must be treated before being pumped into the mains. The usual types are the centrifugal and turbine. On account of their compactness, they are a suitable type for lowering to within the reach of the water in the well, and they are often preferred for low-head pumping. While their efficiency is not as high as some other types, for pumping large volumes of water at a comparatively low lift they give satisfaction. Arkansas City and Newton are examples of cities using this type. The water is pumped from the wells by the Layne & Bowler type of submerged centrifugal pumps as shown in Plate IX, discharging into surface reservoirs; then it is repumped into the distribution system by high-service pumps. At Lawrence, on account of the high iron content of the raw water, the water is first lifted from the wells by a centrifugal pump and discharged through an aërator for the purpose of oxidizing the iron. From the aërator it flows by gravity through two settling basins, and is drawn from the last one by high-service pumps and discharged into the system.

Jet pumps, while not very efficient, are capable of raising large quantities of water through comparatively small holes. In these pumps a jet of liquid is delivered through a restricted throat, drawing with it the water to be lifted, to which the energy of the velocity of the jet is delivered. Air and steam are the principal types, and are simply called air or steam lifts. Many of the plants using deep wells, particularly those in southeastern Kansas, utilize this method of pumping water to the surface, since it is necessary anyway to aërate the water for the removal of the hydrogen sulphide gas. From the surface reservoir it is pumped into the distribution system.

High-service pumping is usually done by means of displacement pumps of the piston or plunger type, and at the plants in Kansas may be seen all kinds, from the single-acting, single-cylinder, horizontal or vertical steam pump, up through com-

pound, duplex and triplex, to the highly developed crank and fly-wheel high-service pumps. Occasionally other types of pumps are used for high-service work, principally impeller pumps of the centrifugal type. It is very common for the smaller plants to install multistage centrifugal pumps for emergency use during fire protection. While these pumps are not efficient for continuous operation, they are cheap in first cost and large volumes of water may be thrown by them at a considerable pressure.

Various types of prime movers for the pumping plants have been adopted. Most of the larger plants depend upon highly developed steam installations for furnishing power, and most of the very small plants depend upon gas, gasoline or oil engines, which may be operated intermittently and started quickly at no great expense. It is quite common to construct combined water and light plants and to drive the generator with either steam or oil engines, or in a few cases with gasoline engines, and do the pumping electrically. At Kingman a steam plant has been developed, driving generators for furnishing both light and power to the city and power for pumping. Large gas engines are also available, directly connected to the triplex pumps, for pumping water in case they are necessary. This is a common type of installation. At Stafford, Belleville, Garden City and many others, the water and light plants have been combined. If the consumption does not demand continuous pumping—and it usually does not in smaller cities—if the pumps are driven by electrical machinery, at times when the current consumption is low, economical operation is secured and the "load curve" is flattened. In other cases, where it is necessary to locate the pumps or wells at some distance from light plants, remote-control motor-driven pumps are used in order to save attendance, as at Arkansas City and Herington. In other cases the city merely owns the wells and buys the current from local electric-light companies for pumping the wells. Such is the case at Concordia. Private companies with large electrical plants are seeking this service, in order to utilize the capacity of the plant at "off peak load" times. The cities of Arkansas City and Newton at the present time are investigating the proposition of electrically pumping the water, securing the current from private companies.

Crude oil engines have somewhat revolutionized the character of prime movers, and in many cases their installation has resulted in unusual saving in the cost of operation of

plants over gasoline engines and steam, particularly in those small plants where the operation is more or less intermittent.

There are three methods of operation of distribution systems in use. The first, direct pressure; the second, indirect pressure; and the third, direct indirect. There are no gravity systems in the state except in one or two cases where the water is delivered to the high-service pumps by gravity. This is the case at Kingman, water being developed in springs some few thousand feet above the city and flowing by gravity to a suction well at the plant in the city, from which it is repumped into the mains.

A direct-pressure system of operation is maintained in most of the larger cities where the consumption warrants the operation of large pumps continually. This system is hardly economical in small or medium-sized cities, on account of the fact that any pump operates with the highest efficiency when it is working under full load. Thus, for instance, if a high-service pump of a capacity to supply a city of 5000 persons is worked to capacity handling the high-consumption period of the day, at night when the consumption drops off the pump is operating under a very small percentage of its full load, and therefore can not be operating efficiently. Where the pumping is balanced, however, this inefficiency may be considerely lessened. The indirect system is used in most of the cities of the state, and consists of pumping water from the supply into an elevated tank, reservoir or standpipe which is at sufficient height to furnish pressure to the city. Ordinarily the reservoir, elevated tank or standpipe is so arranged that it may be cut out in case of fire and water pumped direct. Practically every city has an arrangement of this sort, except possibly three or four of the largest ones.

The direct indirect system is that where an elevated storage tank, reservoir or standpipe of insufficient capacity to supply the consumption for any length of time is used as furnishing a sort of cushion to pump against, equalizing the load on the pumps against variations in consumption, or a supplementary supply to use in case of short accidents. Occasionally a very small plant is built, where the water is pumped into a compressed-air tank and pressure furnished to the city by this means. It is believed that the city of Atwood has the only installation of this kind in the state.

CHAPTER V.

CHEMICAL CHARACTER OF KANSAS WATERS.

The soil and underlying strata of Kansas are largely deposits left by the evaporation of a prehistoric sea, consequently the ground water has every opportunity to take into solution once more these various minerals. Except in a few notable instances, all the water supplies would be classed as hard waters, *i. e.*, have in solution compounds of calcium and magnesium in sufficient quantities to be annoying in the ordinary

PLATE XI. Chemical room, laboratory of Division of Water and Sewage, University of Kansas.

domestic or industrial uses. Many of the waters have sufficient sodium and potassium salts to give a distinct taste. Limestone (calcium and magnesium carbonates) is the predominant rock in the state, and as it goes into solution readily in the presence of carbon dioxide, all waters have as two of their constituents calcium and magnesium bicarbonates.

In an attempt to classify Kansas waters that are used for municipal supplies, according to chemical composition we divide them into five general groups, depending on the predominant compounds found.

GROUP I. Waters having as their principal constituents calcium and magnesium bicarbonates. Many of this type contain ferrous iron held in solution by an excess of carbon dioxide. They have little if any permanent hardness, and in some instances they show an appreciable amount of sodium bicarbonates. Representative waters of this group are:

Bonner Springs.
Lawrence.
Topeka.
Wamego.
Manhattan.
Smith Center.
Belleville.

GROUP II. We place in this group the waters that carry calcium sulphate (gypsum) in solution as well as the bicarbonates. The permanent hardness ($CaSO_4$) varies in these waters from 100 parts per million $CaSO_4$ to 2000 parts per million, depending upon the nearness of the supply to a gypsum deposit. Representative water supplies are:

Marysville.
Holton.
Havensville.
Cottonwood Falls.
Herington.
Marion.
Hanover.
Caldwell.
Larned.

GROUP III. Waters of this group contain sulphates and chlorides of sodium or potassium in addition to bicarbonates of calcium magnesium. In some instances they also contain gypsum. Some of these waters have sufficient sodium chloride to give a distinct saline taste. Representative waters are:

Arkansas City.
Wichita.
Hutchinson.
Great Bend.
Syracuse.

In fact, most of the waters of the Arkansas valley are in this group.

GROUP IV. Waters of this group are found in local deposits of sand or in sandstone. They are comparatively soft waters having small amounts of calcium and magnesium bicarbonate. Representative waters of this group are:

Abilene.
Conway Springs.
Baldwin.
Newton.
Kingman.

GROUP V. This group may be classed as the hydrogen sulphide group. These waters vary considerably in composition, but all have the odor of hydrogen sulphide. In most instances upon aëration they precipitate free sulphur. There is a small

area in the southeastern part of Kansas where deep wells yield waters of this kind. Representative waters of this group are:

Weir City.	Frontenac.
Columbus.	Cherokee.
Pittsburg.	Chetopa.
Girard.	West Mineral.

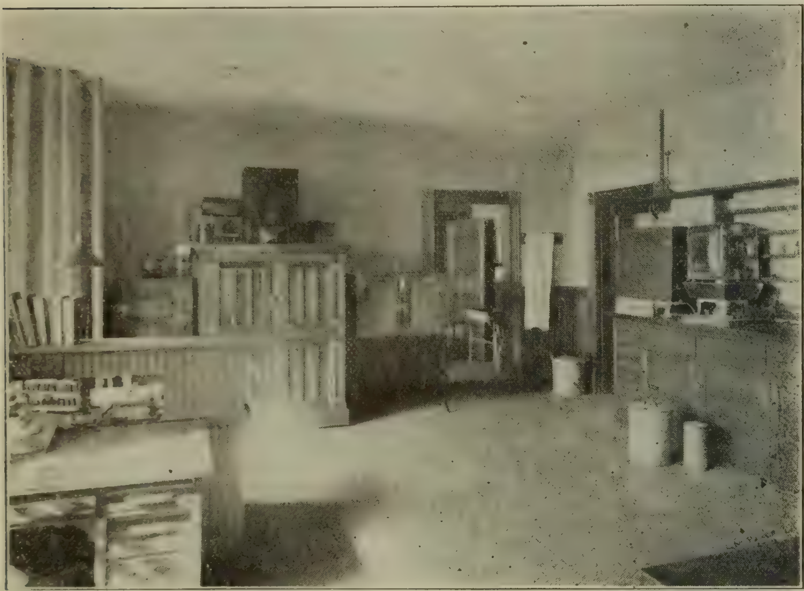


PLATE XIa. Bacteriological room, laboratory of Division of Water and Sewage, University of Kansas.

At best this classification is very rough, as it is impossible to set definite standards for the groups. Although it is impossible to classify definitely as to their chemical composition, it seems reasonable to classify the waters according to hardness and total amount of mineral matter present. To this end we have calculated the calcium and magnesium present to calcium carbonate, and arranged the municipal supplies in order of the magnitude of the value for hardness thus obtained. (See Table II.) These supplies were also arranged in order of the magnitude of the total solids. (See Table III.) From these results the curves were plotted, shown in the diagram (Plate XII). The ordinate is parts per million of total solids for the total-mineral-matter curve. The hardness curve shows a range

of hardness between 46 to 924 parts per million. The total-mineral-matter curve ranges between 124 and 1412 parts per million. For a basis of comparison these curves were divided into groups differing from one another by 50 parts per million. The number of waters falling in each group, on the basis of hardness and total solids, are found in Table IV and Table V, respectively. Taking the middle point in these curves as an average, we found that 307 parts per million of calcium carbonate is the value of which 50 per cent of the waters are less than and 50 per cent are greater than. For total mineral matter the median value was found to be 486 parts per million of solids left on evaporation.

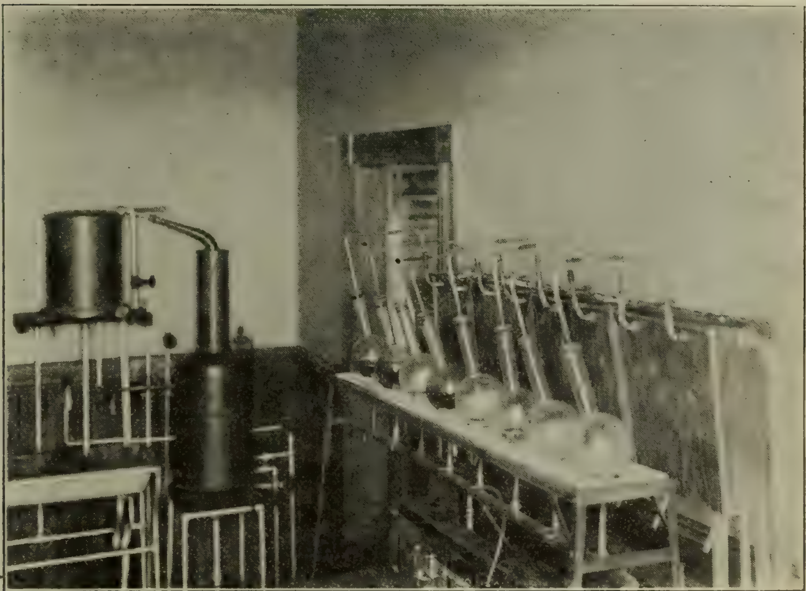


PLATE XI*b*. Ammonia room, laboratory of Division of Water and Sewage, University of Kansas.

In the tables showing the number of waters in each group we found that 23 waters in the hardness table fell between 247 and 296 parts per million calcium carbonate. This is Group V on the chart. In the table for total solids 15 waters fell between 374 and 424 parts per million total mineral matter, or Group VI on the chart. As these waters represent samples taken pretty well over the whole area of the state, it is reasonable to suppose that the law of chance would apply, and that

the waters which occur with the greatest frequency would fall in Group V for hardness and Group VI for total solids. With the median values for hardness and total solids determined, we have a basis for comparison of the municipal water supplies by means of the groups above and below the median line. With this idea in view we have placed below each analysis the group into which the water falls for hardness and total solids.

TABLE II.

Hardness of Ground Water Supplies in Terms of Calcium Carbonate.

Results expressed in parts per million. Arranged in order of magnitude.

Conway Springs	46	West Mineral	252	Chapman	375
Belleville	89	Bunker Hill	253	Kensington	379
Highland	90	Hill City	257	Lawrence	380
Newton	95	Caldwell	258	Sterling	389
Baldwin	96	Eureka	263	Stockton	393
Syracuse	107	Mound Ridge	268	Hutchinson	396
Halstead	117	Junction City	268	Smith Center	397
Kingman	122	Clyde	269	Manhattan	411
Belle Plaine	123	Washington	269	Luray	412
Goodland	131	Holyrood	271	Waterville	414
Bennington	141	Ellinwood	271	Marquette	415
Fowler	149	Burden	274	Logan	416
Abilene	161	Delphos	275	Sabetha	427
Coldwater	162	Seneca	276	Englewood	432
Meade	168	Cherokee	281	Mankato	437
Pittsburg	170	Wakefield	281	Salina	437
Baxter Springs	170	Cawker City	292	Mulvane	439
Scott City	175	Chetopa	293	Scandia	443
Harper	175	Norton	296	Strong City	452
Pratt	179	Oberlin	297	Holton	469
Miltonvale	179	Atwood	299	Lincoln	474
WaKeeney	191	Green	300	Burr Oak	475
Colby	193	Jamestown	302	Hoisington	476
Valley Falls	196	Concordia	307	Onaga	485
Bucklin	197	Lyons	308	Lindsborg	520
Oxford	205	Hiawatha	309	Beloit	531
Clifton	205	Hoisington	312	St. Marys	536
Topeka	207	McPherson	314	Kiowa	539
Oakley	210	Girard	317	Waverly	543
St. John	210	Hays	318	La Cygne	562
Stafford	222	Wilson	321	Waldo	568
Anthony	224	El Dorado	322	Greenleaf	585
Minneapolis	226	Almena	330	Peabody	588
Clearwater	226	Osborne	331	Ellsworth	593
Columbus	228	Great Bend	334	Ashland	595
Phillipsburg	228	Lucas	343	Erie	637
Mulberry	230	Bonner Springs	344	Havensville	644
Glasco	231	Downs	348	Udall	646
Weir City	234	Arkansas City	349	Clay Center	662
Frontenac	238	Wamego	354	Larned	675
Sharon Springs	239	Madison	356	Enterprise	678
Sylvan Grove	240	Wichita	359	Florence	719
Liberal	245	Blue Rapids	365	Marysville	730
Dodge City	246	Kinsley	369	Garden City	802
Ellis	248	Lebanon	369	Glen Elder	870
Plainville	248	Sedan	373	Marion	914
Scammon	251	Kirwin	373	Hanover	924

TABLE III.

Ground Water Supplies—Total Solids Left on Evaporation.

Expressed in parts per million. Arranged in order of magnitude.

Newton	124	Clyde	390	Chapman	587
Kingman	132	Wakefield	399	Wamego	591
Conway Springs	134	Blue Rapids	406	Mankato	613
Baldwin	136	Bonner Springs	409	Mulberry	625
Highland	139	Delphos	414	Garden City	637
Meade	174	Sylvan Grove	415	Englewood	644
Coldwater	178	Manhattan	416	Lindsborg	646
Abilene	185	Washington	420	Lincoln Center	652
Bennington	208	Anthony	421	Kinsley	660
Belle Plaine	209	Cawker	421	Mulvane	674
Baxter Springs	219	Lyons	425	Arkansas City	682
Liberal	246	Sabetha	433	Belleville	682
WaKeeney	254	Lebanon	434	Ellinwood	687
Gas City	260	Stafford	435	Salina	707
Oakley	264	Frontenac	440	Ashland	761
Goodland	264	Scott City	457	Scandia	768
St. John	269	Almena	457	Waverly	785
Halstead	274	Green	459	Chetopa	786
Bucklin	281	Kensington	462	Kiowa	792
Harper	283	Osborne	464	Waldo	796
Hoisington	284	Jamestown	464	Greenleaf	815
Fowler	291	Glasco	466	Peabody	864
Valley Falls	301	Hays	474	Sterling	875
Topeka	302	Kirwin	477	La Cygne	882
Pratt	305	Sharon Springs	486	Erie	882
Oxford	306	Madison	489	Havensville	909
Eureka	307	Clearwater	489	Syracuse	922
Colby	310	Bunker Hill	491	Burr Oak	939
Plainville	328	Strong City	498	Beloit	945
Burden	328	Concordia	504	Florence	958
Pittsburg	329	Wilson	507	Hutchinson	966
Oberlin	330	Wier City	517	Glen Elder	978
Hiawatha	334	Atwood	520	West Mineral	1023
Clifton	341	Waterville	521	Enterprise	1028
Seneca	345	Downs	522	Marysville	1035
Columbus	347	Logan	529	Clay Center	1047
Dodge City	350	Smith Center	534	Luray	1068
El Dorado	354	Phillipsburg	536	Lucas	1120
Frankfort	364	Herington	539	Ellsworth	1126
Miltonvale	365	Lawrence	540	Hanover	1141
Junction City	365	Marquette	541	Marion	1143
Minneapolis	369	Great Bend	542	Sedan	1156
Ellis	373	Onaga	546	Udall	1183
McPherson	379	Hill City	549	Holton	1212
Holyrood	380	Cherokee	555	Wichita	1255
Mound Ridge	381	Caldwell	571	Girard	1310
Norton	381	St. Marys	582	Larned	1412
Scammon	388	Stockton	586		

TABLE IV.

Ground Water Supplies Grouped According to Hardness.

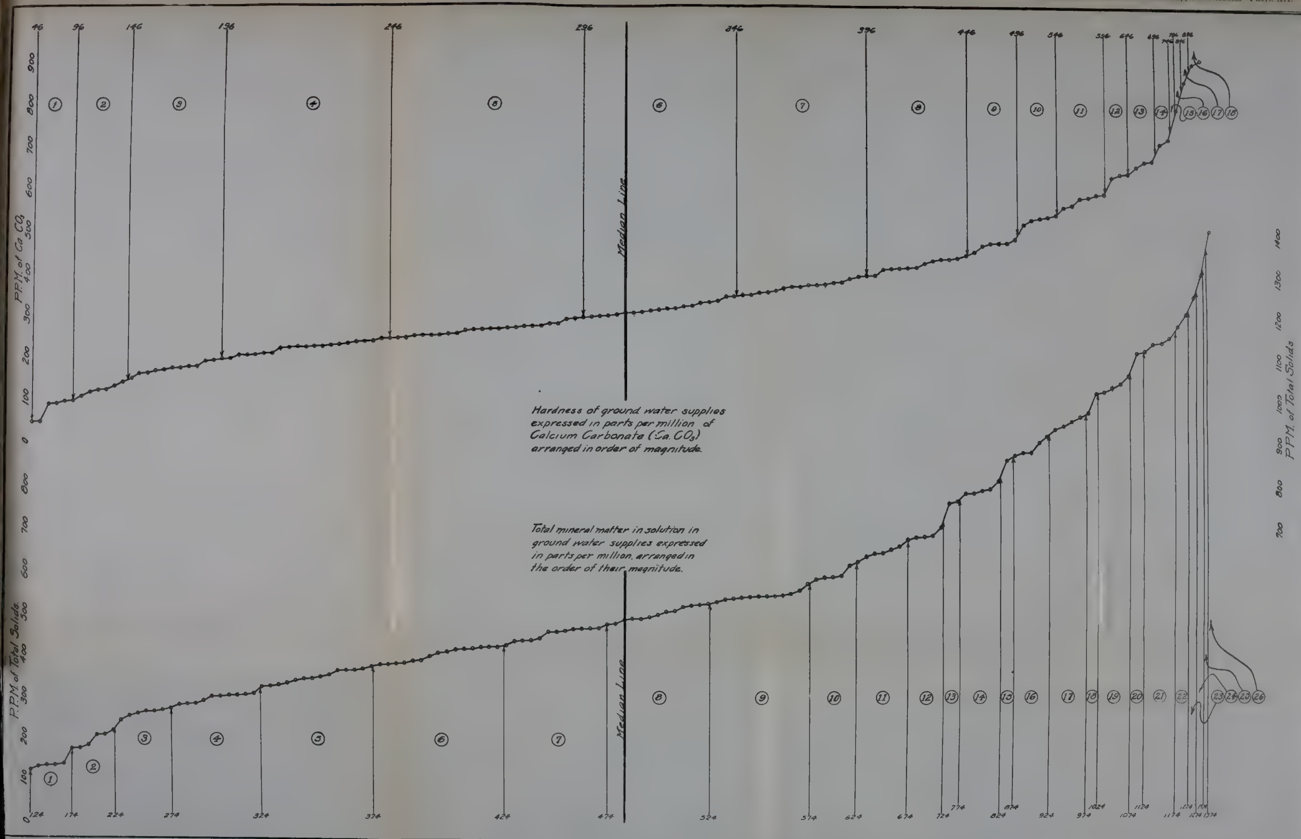
Number of group.	Groups p. p. m. hardness.	Number in group.	Number of group.	Groups p. p. m. hardness.	Number in group.
1	46- 96	6	11	547-596	6
2	97-146	6	12	597-646	3
3	147-196	12	13	547-696	3
4	197-246	20	14	697-746	2
5	247-296	23	15	747-796	0
6	297-346	18	16	797-846	1
7	297-346	18	17	847-896	2
8	397-446	12	18	897-946	2
9	447-496	6			
10	497-546	5			143

TABLE V.

Ground Water Supplies Grouped According to Total Mineral Matter in Solution.

Number of group.	Groups p. p. m. total dissolved solids.	Number in group.	Number of group.	Groups p. p. m. total dissolved solids.	Number in group.
1	124- 174	6	15	825- 874	1
2	175- 224	5	16	875- 924	5
3	225- 274	7	17	925- 974	4
4	275- 324	10	18	975-1024	2
5	325- 374	14	19	1025-1074	4
6	375- 424	15	20	1075-1124	1
7	425- 474	13	21	1125-1174	4
8	475- 524	12	22	1175-1224	2
9	525- 574	12	23	1225-1274	1
10	575- 624	5	24	1275-1324	1
11	625- 674	7	25	1325-1374	0
12	675- 724	4	26	1375- —	1
13	725- 774	2			
14	775- 824	5			143

Taking the median value for hardness (307 parts per million calcium carbonate) as the average water, we have a value that can be used in discussing the hard-water problems that must be met in the near future by nearly every city in the state. Up to the present time municipalities have attemped to obtain the softest water available in sufficient quantities, but no thought has been given to the methods of treating these waters to remove objectionable minerals. That hard waters for city supplies have been accepted as a matter of course is possibly due to the fact that it is not popularly known that the hardness is the cause of great economic wastes and that


P.P.M. of Ca CO3
Median Line
Hardness of ground water supplies expressed in parts per million of Calcium Carbonate (Ca CO3) arranged in order of magnitude.
Total mineral matter in solution in ground water supplies expressed in parts per million, arranged in the order of their magnitude.
Median Line
P.P.M. of Total Solids
P.P.M. of Total Solids

waters can be softened economically for municipal use. The Department of State Chemical Research of the University of Kansas is making a complete and exhaustive study of water softening as applied to Kansas conditions, and the findings will be published in another bulletin of this series, so necessarily the discussion that follows will be very brief and quite general in nature.

For removal from the water of objectionable hardening constituents mentioned in the preceding chapter, advantage is taken of the fact that calcium carbonate and magnesium hydroxide are nearly insoluble and that these compounds are easily secured by the mixing of lime and soda ash in proper quantities with the water to be softened. Amounts of these chemicals can be calculated definitely from the results of mineral analysis of the water in question. Before treatment the waters may contain compounds of iron, calcium, magnesium and sodium, combined with carbonic, sulphuric, hydrochloric or nitric acid. The treatment substitutes for the compounds of iron, calcium and magnesium, salts of sodium, which have no hardening properties. More correctly speaking, the water will contain the ions corresponding to the compounds mentioned above. The lime treatment removes the temporary hardness (or that which can be removed by boiling) and the soda ash the permanent hardness (or that which can not be removed by boiling). The following are the reactions for removing the temporary hardness with lime:

CO_2 Carbon dioxide.	+	$Ca(OH)_2$ Calcium hydroxide.	=	$CaCO_3$ Calcium Carbonate.	+	H_2O Water.
$CaCO_3 \cdot CO_2$ Calcium bicarbonate.	+	$Ca(OH)_2$	=	$2\ CaCO_3$	+	H_2O
$MgCO_3 \cdot CO_2$ Magnesium bicarbonate.	+	$Ca(OH)_2$	=	$MgCO_3$ Magnesium carbonate.	+	$CaCO_3 + H_2O$
$MgCO_3$ Magnesium carbonate.	+	$Ca(OH)_2$	=	$Mg(OH)_2$ Magnesium hydroxide.	+	$CaCO_3$
$MgSO_4$ Magnesium sulphate.	+	$Ca(OH)_2$	=	$Mg(OH)_2$	+	$CaSO_4$ Calcium sulphate.

These are perfectly definite and quantitative reactions.

The following are the reactions for removal of permanent hardness with sodium carbonate (soda ash):

$MgSO_4$ Magnesium sulphate.	+	Na_2CO_3 Sodium carbonate.	=	$MgCO_3$ Magnesium carbonate.	+	Na_2SO_4 Sodium sulphate.
$MgCO_3$ Magnesium carbonate.	+	$Ca(OH)_2$ Calcium hydroxide.	=	$CaCO_3$ Calcium carbonate.	+	$Mg(OH)_2$ Magnesium hydroxide.
$CaSO_4$ Calcium sulphate.	+	Na_2CO_3 Sodium carbonate.	=	$CaCO_3$ Calcium carbonate.	+	Na_2SO_4 Sodium sulphate.

Note that the $MgSO_4$ is first converted into $MgCO_3$, which is soluble, and then into $Mg(OH)_2$, which is insoluble. In other words, it requires one equivalent of Na_2CO_3 as well as one equivalent of CaO to remove one equivalent of $MgSO_4$. This is why $MgSO_4$ appears in both sets of reactions.

Note also that with $MgCO_3 \cdot CO_2$ it requires one equivalent of CaO to remove the CO_2, *i. e.*, react with the bicarbonates; and one equivalent of CaO to remove the $MgCo_3$ formed, as $Mg(OH)_2$.

It is impossible to definitely measure in dollars and cents the total saving to any municipality by substituting a soft for a hard water, as there are many and varied detrimental effects caused by hard water. The most apparent deleterious effects of hard water are experienced in the power plant, in the laundry, on plumbing fixtures, and in general household uses of water. There is also a great depreciation of the physical value of the water plant itself.

In a power plant hard water may cause foaming, priming, corrosion, pitting, grooving or scaling, all of which are sources of great loss to the plant. Formation of scale by minerals precipitated from the water is the greatest source of loss. Mr. Stromeyer* reports the following results of loss of heat due to scale:

Thickness of scale in inches..........	1/64 in.	1/32 in.	1/8 in.	3/8 in.
	2%	4%	9%	48%

The losses in time and repairs are so great that practically every industrial establishment in Kansas would be benefited by the installation of some method of softening water. The railroads have long since met this waste by building their own softeners.

In the laundry, wear and tear on clothes and soap consumption are enormous when using hard waters. In fact, the waste

* Proc. M. E., 1903.

from this one domestic operation alone is sufficient to make a municipal water softening plant a profitable investment.

The life of plumbing fixtures is much shorter with the use of hard water than with soft. Figures taken from statistics compiled by plumbing companies show that the cost of repairs that result directly from hard water can be estimated at approximately one dollar per capita per year in a city having a water with the median hardness of 307 parts per million of calcium carbonate.

The experiences of every housewife with hard water are so familiar that it is unnecessary to describe them. However, the waste of soap in dollars per capita is not so well known. Soap is a definite chemical compound of sodium with a fatty acid, and reacts with the calcium and magnesium in the water, precipitating an insoluble calcium or magnesium soap. Therefore, a lather is obtained only after all of the calcium and magnesium are removed. Prof. Geo. C. Whipple, in his book, "The Value of Pure Water," estimates that each person in an ordinary household will soften completely one and one-half gallons of water with soap per day. This includes dish washing, laundry work, baths and other personal ablutions. That this is a conservative estimate is evident. We will take 400 gallons softened per annum as a foundation for our estimate of soap waste per capita when using a water of median hardness. One pound of soap will soften completely ten gallons of such a water. Figuring soap at five cents a pound, the cost of softening to a point when a lather is obtained will be $2 per capita per annum. After softening this water, the soap consumption before a lather is obtained would be practically nothing. A plant large enough to soften water for 10,000 people would cost approximately $30,000. Figuring all overhead charges, upkeep, operating expenses, etc., this $2 per capita waste would build the plant, maintain and pay for it in less than five years' time. This one item of soap consumption alone would, therefore, be sufficient reason to build a water-softening plant in a city having hard water.

Add to this loss per capita, plumbing repairs, maintenance of cisterns, wear and tear on clothes, and numerous losses of time and material, one finds that the 375,500 people in the state using municipal ground-water supplies are in the aggregate throwing away a very large sum of money—more than one million dollars per year.

SCOPE OF ANALYSIS AND INTERPRETATION OF RESULTS.

The analytical work done on a water sample may be divided into three classes:

1. Sanitary bacterial examination.
2. Sanitary analysis.
3. Technical chemical or mineral analysis.

This complete examination is necessary to determine the quality of the water for municipal use.

1. SANITARY BACTERIAL EXAMINATION.—(*a*) Total number of bacteria per cubic centimeter grown on gelatin at 20° C. (*b*) Total number of bacteria per cubic centimeter grown on agar at 37° C. (*c*) Approximate number of organisms of the *B. coli* group. (*d*) Confirmatory tests for *Bacillus coli.*

2. SANITARY ANALYSIS.—(*a*) Physical determinations: temperature; color; odor; and turbidity. (*b*) Chemical determinations: oxygen consumed; nitrogen as albuminoid ammonia; nitrogen as free ammonia; nitrogen as nitrites; nitrogen as nitrates; and dissolved gases.

3. MINERAL OR TECHNICAL ANALYSIS.—Determinations of

Silica, reported as	SiO_2
Iron, reported as	Fe_2O_3
Aluminum, reported as	Al_2O_3
Calcium, reported as	Ca
Magnesium, reported as	Mg
Sodium and potassium, reported as	Na+K
Chlorine, reported as	Cl
Sulphates, reported as	SO_4
Bicarbonates, reported as	HCO_3
Carbonates, reported as	CO_3
Solids, reported as	Total
Solids, reported as	Dissolved
Solids, reported as	Suspended

The results of sanitary and mineral analyses are reported in parts per million of the substances present. One part per million is equivalent to one pound per million pounds of water.

SCOPE AND INTERPRETATION OF BACTERIOLOGICAL ANALYSIS.

"Sanitary examination of water is made along two distinct lines—bacteriological and chemical. The former attempts to

show the presence or absence of sewage contamination through the finding of living bacteria that are characteristic of sewage. A sanitary chemical analysis, on the other hand, does not take living bacteria into consideration, but attempts to show by the presence or proportion of certain chemical substances that sewage has found entrance into a water supply.

"As the constituents of sewage-contaminated water that are directly detrimental to human safety are the pathogenic microbes of some infectious disease, the most direct evidence of the unfitness of such water for human consumption would be the detection of such microbes in a water supply.

"All sewage and sewage-contaminated water, however, contains the wastes from human bodies, and as such waters are almost sure, sooner or later, to contain the bacteria of infectious disease, the demonstration of merely the presence of fresh sewage in a water supply is enough to condemn it. For this reason, most of the bacteriological examination is directed toward detecting microbes that normally inhabit the intestine instead of detecting those of specific disease. This is a safe procedure, since water-borne diseases, such as typhoid, dysentery and cholera, have their seat of activity in the intestine. Specific organisms of these diseases have come from persons specifically affected; hence there is more or less uncertainty attending the search for such bacteria unless there is an epidemic. The specific disease microbes, however, are always associated with those normally found in the intestine, so that for the purposes of sanitary analysis, the presence of the latter implies the former. The normal intestinal bacteria that serve as a basis for the detection of sewage contamination are those belonging to the *Bacillus coli* group."*

To properly judge a sample of water one must not only detect the presence of the *Bacillus coli* group, but must find the approximate number of these bacteria. This is done by making accurate dilutions of the water and isolating the organism from the smallest amount of water possible.

SCOPE AND INTERPRETATION OF SANITARY CHEMICAL ANALYSIS.

The chemical determinations that in general constitute a sanitary chemical analysis are: the amount and character of suspended matter; oxygen consumed; oxygen dissolved; nitrogen as albuminoid ammonia (so-called) ; nitrogen as free am-

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* Circular No. I, State Water Survey.

monia; nitrogen as nitrites; nitrogen as nitrates; and chlorine. The results are expressed in parts of the substance determined in a million parts of water.

The object of these determinations is to find out whether or not organic material from sewage has gained entrance to the source from which the water of any supply is drawn.

Organic matter of this kind is readily acted upon by bacteria, and, during the decomposition, compounds are formed which can be identified and determined with accuracy by chemical methods. The decomposition products of nitrogen-containing organic matter are the ones that can be determined most accurately.

Nitrogen in albumin-like compounds (or that which is liberated by alkaline potassium permanganate) indicates the presence or absence of undecomposed animal or vegetable material containing proteins. Any abnormal amount of these compounds shows that the water is polluted.

Nitrogen as free ammonia in any considerable quantity shows that the bacterial action on the protein compounds has been carried further, and that ammonia compounds or urea are present. Some exceptions to this statement are well known.

Nitrogen as nitrites yields the information that the bacterial process has gone a step further, and that the oxidation of the nitrogen is taking place; or, in case nitrates are present, that reduction has probably been going on.

Nitrogen as nitrates shows that the organic material has been completely transformed to a mineral salt which is relatively stable.

On the Atlantic coast the chlorine determination is of great value as an indicator of contamination by animal excrement (urine contains salt), for every district has a normal value for chlorine. Any excess over this normal amount shows that the water is receiving drainage which probably contains urine. The determination is of little value in the Middle West on account of the salt beds underlying the country.

The oxygen consumed tells us how much oxygen is necessary to completely oxidize any undecomposed organic matter. The oxygen dissolved is the amount of oxygen in the water available for use in oxidation, if given time.

One can not set a standard for the exact amount of any or all

of these substances that are allowable in a water. Each analyst must judge whether or not the water is contaminated from the relative amounts as shown by the analyses.

From this statement it will be apparent that it is ridiculous to express the results of analysis in *per cent of purity*. It is misleading to say that a water is 99.96 per cent pure, for, as a matter of fact, the sewage from a city does not often vary more than one-hundredth of a per cent from the water supply.

SCOPE OF A TECHNICAL ANALYSIS OF WATER.

Every natural water contains some minerals in solution which affect more or less, depending on their nature, the value of a water for domestic or industrial supply. It is the object of a technical analysis to determine how much and what kind of salts are present.

Hard waters are those containing calcium (lime) and magnesium salts or iron in sufficient quantities to interfere in steam-making or general household use. Their soap-destroying power is enormous.

Temporary hardness is that portion of the salts dissolved in a water that can be removed on boiling. These salts are calcium bicarbonate and magnesium bicarbonate. The calcium (Ca), magnesium (Mg) and hydrocarbonate (HCO_3) determinations give us the desired information.

Permanent hardness is that portion of the salts which remains in solution after boiling. They are usually calcium sulphate, magnesium sulphate, calcium chloride, magnesium chloride, calcium nitrate, and magnesium nitrate. The sulphate (SO_4), nitrate (NO_3), chlorine (Cl), are the determinations, in addition to the temporary hardness, necessary to find the permanent hardness.

Iron discolors plumbing fixtures, fabrics in washing, tea and coffee in cooking, and imparts an inky taste to the water.

Soluble salts of sodium and potassium may be present in a water in sufficient amounts so that they are detrimental to steam making, or give the water a disagreeable salty taste.

BACTERIAL STANDARDS OF PURITY.

Total bacteria on agar at 37° C., less than 250.

Total bacteria on gelatine at 20° C., less than 1000.

Organisms of the *B. coli* group should be absent in one cubic centimeter of samples. When these organisms appear in more

than 30 per cent of one cubic centimeter of samples, the water is considered unfit for domestic consumption.

Proposed limits of impurities:

	Parts per million.
Turbidity	Clear
Color	None
Odor	None*
Total solids	500
Hardness	300
Oxygen consumed	2 to 5
Nitrogen as albuminoid ammonia	.1
Nitrogen as free ammonia	.07
Nitrogen as nitrites	.001
Nitrogen as nitrates	2 to 4

The "Standard Methods of Water Analysis" of the American Public Health Association were followed in general.

NOTE.—The analyses accompanying the description of each plant were made on samples sent in by city officials voluntarily. Therefore, in some instances complete analyses are missing on acount of improper samples.

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* Excepting deep wells in southeastern Kansas that carry hydrogen sulphide (H_2S).

CHAPTER VI.

Details Concerning Kansas Ground Water Supplies.

Many of the waterworks plants in the state were built either by municipalities or by private individuals during the "boom" days of the latter eighties, and equipped for cities several times the size of what they eventually turned out to be. On account of heavy debts settled on to them at that time, the plants have never had any extensive improvements added since, with the result that at the present time they are wholly inadequate for the services necessary, and are inefficient in operation. In some cases large distributing mains are lying idle in country fields. Practically all of the more recent plants, however, have been built under municipal ownership with the services of competent engineers.

On account, possibly, of what has been termed the "rising sanitary standard," the last few years have seen a remarkable change both in the improvement of old plants and in the construction of new. In many cases the sources of supply have been changed or developed until there are very few at the present time which are not adequate both in point of quantity and quality. Many plants constructed originally to utilize ground water have been changed to surface water, with proper purification plants, and, in some cases, plants constructed to use surface water in the early days, with ancient or impossible purification plants, have changed to ground water. The whole scheme generally works out along the line of experience. Of the more recent plants, some of the cities have not deemed it necessary to secure engineers until after the bonds have been voted, and others have secured unscrupulous engineers, and have consequently been victimized. These are very few in number, however. Single pumping and power units, small-sized and inadequate pipes and inefficient plants are not the rule. Particular attention has been paid by the Division of Water and Sewage of the State Board of Health since 1907, when it was created, and through which department the plans must pass before permits may be issued, to securing not only pure and wholesome water for domestic use, but also sufficient quantity and adequate plants for fire protection.

Scientific rate making for waterworks plants is practically unknown in this state. Ordinarily the rates charged for water

depend upon the rates charged in some neighboring city, or are made as high as the people will pay. The financial management of the waterworks plants is of great importance to the individuals of a community, since upon that management depends not only the question of rates, but to a certain extent other forms of taxation. The expense connected with waterworks plants should be equally distributed, both with respect to individuals at the present time and with respect to future generations. The yearly expenses of the plant should be included under the following heads: First, interest on the investment; second, operating and maintenance; third, sinking fund for liquidating the bonded debt; fourth, depreciation fund; fifth, extensions and improvements; and sixth, in case of privately owned plants, profit. The object of a municipal plant, however, is not profit, but service at the lowest consistent rate. The functions performed by waterworks plants are to furnish water for private use, fire protection to property, and public use such as sprinkling, sewer flushing, parks, etc. From these sources the revenue must be obtained to offset the expenses given before. The proper proportion of revenue requires very careful consideration. The most equitable method is probably by the meter system, since the rate should be made so that each service is charged with only the amount of water used plus a very small addition for its proportion of that amount of water which is recorded at the pumping station but can not be accounted for—loss by leakage, etc.

Naturally, very large quantities of water can be furnished cheaper per unit of volume than small quantities; therefore, higher rates are charged to the consumer who uses only small amounts of water than to the manufacturer who uses large quantities. On the other hand, a very large proportion of the total cost of the plant is spent wholly for fire protection, for practically all of the consumers along any main could be supplied through a main very much smaller, and the pumps at the station could supply water to a great many more persons than ordinarily use it; but on account of the functions of the plant, a large investment must be made so that fire protection may be available when needed. That proportion of the plant which is primarily for fire protection should be paid for by the city at large, and, while it is sometimes taken care of by a small amount charged for fire-hydrant rental, and the balance made

up by a tax levy, it will be noticed that in many of the cities of the state no hydrant rental is charged against the city at large for the benefit of the waterworks plant, thus either forcing the consumer to pay for protection on his neighbor's property which is not supplied with water, or resulting in the unscientific manner of dividing the deficit up among all property by taxation.

In general, the proportion of the total expenses of the plant which should be paid by the city at large for fire protection amounts to between 40 per cent and 50 per cent. This is somewhat in excess of that which has generally been recognized, but expert commissions studying the question thoroughly have arrived at the decision that the proportion paid for fire protection in most cases is too low. The ordinary method depends upon charging a certain amount for each fire hydrant. A still better method would be to charge each property a certain amount, depending upon the fire risk from the character of the property and the protection afforded it by the layout of the plant and distribution system. Each case, however, is a problem in itself, and the proportion depends upon the conditions.

A recent case was investigated by the writer in a small Oklahoma city, in which only a small percentage of the total population of the city took water from the municipally owned plant, and a great deal of free water was given a school and to the city for sprinkling, etc.; also, a large amount of water was sold to a neighboring city, and delivered at a price which is very probably cheaper than the water could be pumped for. The result is that those persons who use water from the plant, paying for it under the rates of the city, are paying not only for the water they use and for the service afforded them, but for the water used for public purposes, the water used for the large private school, and very probably for some of the water used by the consumers in the neighboring city. This, of course, is unusual, but it cites the unfairness with which some plants are operated.

Meters are coming to be generally used both by private companies and by municipalities in Kansas, although many plants have only made the first step in this direction. The water rates vary for the ordinary individual consumer from 10 cents to as high as 45 cents per thousand gallons. The large consumers

pay from 5 cents per thousand gallons up, depending to a great extent upon the amount of water used. Practically every city has a sliding scale which permits lower rates when large quantities of water are used. Fire hydrants are charged for in all privately owned plants and in some of the municipal plants, at rates varying from merely a nominal charge per hydrant to an average of about $40 per year per hydrant. Practically always the total amount secured from hydrant rental is too low, due possibly to the inclination to underdevelop the fire-protection side of the plant when a certain amount is charged per hydrant. Meters generally should be owned by the company and should be installed on the basis of a minimum monthly charge, in order that uniformity in styles of meters may be secured, that friction between the officials and the consumer may be avoided, and that efficient repair plants may be maintained for keeping the meters in repair. Ordinarily the rates are based upon a minimum charge of 50 cents or 75 cents per month meter rental, allowing usually 2500 or 3000 gallons for this amount, with a sliding scale for amounts in excess. Where flat rates are in effect the charge is usually made either for the purpose for which the water is used or a certain amount per fixture.

Table VI, showing some of the details of the ground water supplies tabulated, follows. This table will be amplified upon somewhat and arranged to include all water supplies of the state in the next bulletin, entitled "Surface Water Supplies of Kansas."

TABLE VI.

Details of Kansas Ground Water Supplies.

City.	Population 1910.	Number of connections.	Population per connection.	Per cent of connections metered.	Consumption in gallons per day.	Consumption in gallons per day per capita.	Sewers.	Minimum monthly rate.	Rate per 1,000 gallons.	Tons of pipe.	Tons per capita.	Tons per fire hydrant.
CITIES OF LESS THAN 1000 POPULATION, CENSUS OF 1910.												
Almena	702	90	8	100	....	....	No.	$0.50	$0.15	231	.33	10.00
Alton*	414	....	....	....	....	....	No.	....	....	195.9	.47	6.80
Ashland	910	....	....	....	....	....	No.	....	....	205	.22	9.80
Atwood	680	82	8	75	68,000	100	No.	.50	.15	79.8	.12	5.31
Belle Plaine	850	110	8	92	40,000	47	No.	.75	.25	239	.28	7.50
Bennington*	386	23	17	100	2,000	50	No.	.50	.20	157	.41	6.03
Bucklin	696	115	6	100	30,000	43	No.	1.00	.15	228	.33	9.95
Bunker Hill	242	....	....	....	....	....	No.	1.00	....	143	.59	....
Burden	424	136	3	92	12,000	28	No.	.50	.27	261	.62	16.30
Cawker City	870	115	8	90	75,000	87	No.	.50	.15	229	.26	4.77
Chapman	781	68	11.5	10	10,000	13	No.	.75	.375	384	.49	12.80
Cimarron*	587	30	20	100	....	....	No.	....	.15	169	.29	7.37
Clearwater	569	60	10	100	25,000	44	No.	1.00	.20	157	.28	6.82
Clifton	614	100	6.1	15	45,000	73	No.	.24	.20	127	.21	4.54
Coldwater	684	125	6	100	15,000	22	No.	1.00	.25	208	.30	10.41
Cottonwood Falls	899	....	....	....	....	....	No.	....	....	....	....	....
Ellinwood	976	95	10	100	20,000	21	No.	.75	.15	208	.22	9.46
Englewood	518	48	11	35	....	....	No.	1.25	.50	134	.26	7.45

Enterprise	706	105	6.7	100	35,000	50	No.	.50	.15	115	.16	6.40
Esbon*	347	...	...	...	...	...	No.	...	...	221.5	.64	...
Fowler*	473	...	...	...	...	...	No.	...	...	115	.24	5.00
Glasco	720	102	7	100	40,000	56	No.	.75	.20	171	.14	7.14
Green	289	...	...	...	...	...	No.	...	...	...	...	...
Glen Elder	565	...	...	...	...	...	No.	...	...	...	...	...
Greenleaf	781	245	3	15	100,000	128	No.	.67	.15	222	.28	7.94
Havensville	412	58	7	98	10,000	25	No.	.50	.30	64	.15	4.92
Highland*	763	40	19	...	...	...	No.	.50	.30	...	...	...
Hill City	983	89	11	...	60,000	61	No.	.50	.10	...	...	...
Holyrood	361	55	7	95	...	...	No.	.33	.15	114	.30	4.75
Jamestown	462	112	5	75	18,000	39	No.	.75	.30	127	.27	15.90
Jetmore*	317	...	...	...	...	...	No.	...	...	...	...	...
Kanopolis*	577	...	...	...	...	...	No.	.30	.25	214	.32	6.49
Kensington	497	141	4	100	40,000	80	No.	.50	.15	167.5	.34	6.45
Kirwin	626	...	...	...	...	...	No.	...	...	...	...	...
La Cygne	957	100	10	34	20,000	21	No.	.50	.25	416	.44	18.10
Lebanon	731	135	5	100	15,000	21	No.	.835	.35	395	.54	26.30
Logan	714	125	6	90	9,000	136	No.	.50	.15	123	.17	8.20
Lucas	573	...	...	...	...	...	No.	...	...	201	.35	10.00
Luray*	341	...	...	...	...	...	No.	1.00	.20	...	...	...
Madison*	721	14	51	100	...	...	No.	.75	.35	238	.33	6.26
Marquette	715	...	...	...	...	...	No.	...	...	...	...	...
Meade	664	140	5	100	60,000	90	No.	.75	.30	124	.19	6.90
Miltonvale	829	75	11	100	40,000	48.3	No.	.75	.25	200	.24	9.53

TABLE VI—Continued.

City.	Population 1910.	Number of connections.	Population per connection.	Per cent of connections metered.	Consumption in gallons per day.	Consumption in gallons per day per capita.	Sewers.	Minimum monthly rate.	Rate per 1,000 gallons.	Tons of pipe.	Tons per capita.	Tons per fire hydrant.
CITIES OF LESS THAN 1000 POPULATION, CENSUS OF 1910.												
Moline	808	11	73	100	....	....	No.	$0.333	$0.25	121	.15	5.50
Moundridge	626	110	6	100	15,000	24	No.	.50	.30	125	.20	5.21
Mulberry	997	143	7	34	30,000	30	No.	.60	.30	185	.19	7.40
Oakley	681	....	....	....	....	....	No.	....	....	....	....	....
Onaga	759	....	....	....	....	....	No.	....	....	....	....	....
Oxford	624	36	17	100	10,000	16	No.	....	.25	199	.32	6.90
Protection*	390	....	....	....	....	....	No.	....	....	205	.52	9.30
St. Francis	492	....	....	....	....	....	No.	....	....	....	....	....
Scandia	579	62	9.4	....	....	....	No.	.60	.10	163	.28	7.08
Scott City	918	21	44	100	25,000	270	No.	.75	.10	218	.24	6.61
Sedgwick	626	60	10.2	100	....	....	No.	.75	.25	....	....	....
Sharon Springs	440	....	....	....	....	....	No.	....	....	....	....	....
Strong City*	762	....	....	100	....	....	No.	.25	.50	224	.29	8.30
Sylvan Grove	464	136	3.4	100	38,000	82	No.	1.00	.25	139	.30	10.70
Turon	572	....	....	....	....	....	No.	....	....	....	....	....
Udall	330	8	41.0	25	500	....	No.	.50	.50	....	....	....
Wa Keeney	883	121	7.3	100	100,000	113	No.	....	.15	....	....	....
Wakefield	574	112	5.1	100	40,000	70	No.	....	.125	....	....	....
Waterville	704	44	16	100	7,000	10	No.	.50	.30	196	.28	9.80

Waverly	751	65	11.6	100	10,000	13	No.	.75	.50	72	.096	5.53
Westmoreland*	484	....	....	....	....	....	No.	....	....	169	.35	7.40
Wilson	981	210	5	100	75,000	77	No.	.25	.25	....	....	....

*Plant just completed or under construction.

CITIES OF MORE THAN 1000 AND LESS THAN 2000 POPULATION.

Altoona	1,462	96	17.7	9	30,000	18	No.	$0.50	$0.35	196	.12	14.00
Baldwin City	1,386	225	6.5	100	40,000	29	Yes.	.75	.27	506	.37	10.10
Baxter Springs	1,598	270	5.9	20	20,000	13	No.	.50	.50	....	....	....
Blue Rapids	1,756	230	7.6	100	160,000	91	No.	.50	.25	284	.16	11.40
Bonner Springs	1,462	138	10.6	100	60,000	41	Yes.	.50	.30	242	.17	6.90
Burr Oak	1,132	88	13	100	25,000	22	No.	.50	.20	272	.24	8.50
Cherokee	1,452	327	4.5	33	115,000	79	No.	.50	.50	318	.22	9.40
Chetopa	1,548	250	6.2	10	....	....	No.	.50	.50	170	.11	6.50
Colby	1,130	108	10	100	35,000	31	No.	.50	.25	430	.38	9.20
Conway Springs	1,292	160	8.1	100	80,000	62	No.	1.00	2.05	135	.10	10.40
Downs	1,427	250	6	100	100,000	70	No.	....	.20	300	.21	9.70
Ellis	1,404	115	12.2	100	50,000	36	No.	1.00	.15	170	.12	4.30
Erie	1,300	220	5.9	100	75,000	58	Yes.	.50	.30	279	21	8.00
Frankfort	1,426	205	7.0	100	75,000	53	Yes.	.35	.40	218	.15	6.20
Goodland	1,993	503	4.0	100	75,000	38	No.	.75	.30	554	.28	13.50
Halstead	1,004	217	4.6	100	40,000	40	Yes.	.50	1.62	467	.47	11.70
Hanover	1,039	140	8.0	30	10,000	10	No.	.333	.25	275	.27	8.90
Harper	1,638	250	7	100	200,000	122	Yes.	.75	.15	....	....	....
Hoisington	1,975	390	5.1	100	100,000	51	Yes.	.50	.20	387	.20	7.30
Kinsley	1,547	225	6.9	90	90,000	58	Yes.	1.00	.15	....	....	....

TABLE VI—CONTINUED.

City.	Population 1910.	Number of connections.	Population per connection.	Per cent of connections metered.	Consumption in gallons per day.	Consumption in gallons per day per capita.	Sewers.	Minimum monthly rate.	Rate per 1,000 gallons.	Tons of pipe.	Tons per capita.	Tons per fire hydrant.
CITIES OF MORE THAN 1000 AND LESS THAN 2000 POPULATION.												
Liberal	1,716	300	5.7	37	35,000	20	No.	$1.00	$1.00	......	......	......
Lincoln	1,508	261	5.8	100	160,000	106	No.	.50	.15	182	.12	......
Lindsborg	1,939	361	5.4	98	260,000	134	Yes.	.50	.25	......	......	......
Mankato	1,155	200	5.8	60	35,000	30	No.	.67	1.50	178	.15	7.10
Marion	1,841	250	7.4	100	30,000	16	Yes.	......	......	617	.33	14.70
Medicine Lodge	1,200	......	......	......	......	......	No.	......	......	......	......	......
Minneapolis	1,895	500	3.8	100	300,000	158	Yes.	.50	.25	533	.28	8.50
Mulvane	1,084	115	9.4	100	100,000	92	Yes.	.50	.25	......	......	......
Nickerson*	1,195	......	......	......	......	......	Yes.	.75	.10	328	.28	9.70
Norton	1,787	362	4.9	100	90,000	50	No.	.67	.24	522	.29	12.70
Oberlin	1,157	114	10.1	100	......	......	No.	......	......	274	.24	10.10
Osborne	1,566	300	5.2	75	......	......	No.	.75	.15	......	......	......
Peabody	1,416	200	7.1	100	45,000	32	Yes.	.50	.30	274	.19	6.70
Plainville	1,090	124	......	100	......	......	No.	.415	15	......	......	......
Sabetha	1,768	255	6.9	100	93,225	53	Yes.	.50	.30	538	.30	7.70
St. John	1,785	268	6.7	95	56,000	31	Yes.	.15	.15	1,013	.57	23.60
St. Marys	1,610	160	10.0	......	100,000	62	No.	.55	.40	179	.11	3.10
Seneca	1,806	350	5.2	......	120,000	67	Yes.	......	......	577	.32	4.60
Stafford	1,927	......	......	......	......	......	Yes.	......	......	278	.14	11.10

Stockton	1,317	355	3.7	...	150,000	114	No.	.42	.15	257	.20	7.80
Syracuse	1,126	150	7.5	100	30,000	27	No.	1.50	.15	210	.19	7.80
Valley Falls	1,129	...	...	...	...	...	No.	...	...	...	...	...
Wamego	1,714	403	4.3	100	92.000	54	No.	.25	.20	126	.074	2.90
Weir City	11,770	...	...	...	...	...	No.	...	...	280	.16	*...

*Plant just completed or under construction.

CITIES OF MORE THAN 2000 AND LESS THAN 3000 POPULATION.

Anthony	2,669	...	...	...	...	...	No.	...	$0.15	882	.33	11.70
Belleville	2,224	458	4.9	18	70,000	32	No.	$0.90	.50	403	.19	8.40
Caldwell	2,205	369	6.0	99	550,000	250	Yes.	.50	.20	607	.27	8.40
Ellsworth	2,041	321	6.4	100	51,000	25	No.	.50	.30	431	.21	6.60
Eureka	2,333	500	4.7	100	150,000	64	Yes.	...	.35	...	...	...
Girard	2,446	325	7.5	75	120,000	49	Yes.	.75	.375	285	.12	4.80
Hiawatha	2,974	565	5.3	95	190,000	64	Yes.	.25	.30	800	.27	14.00
Holton	2,842	323	8.8	100	150,000	53	Yes.	.60	.30	514	.18	12.20
Humboldt	2,548	250	10.2	...	100,000	39	Yes.	...	.25	486	.19	9.00
Kingman	2,570	535	4.8	95	230,000	89	Yes.	.50	.125	439	.17	8.40
Larned	2,910	540	5.4	99	150,000	52	Yes.	.50	.50	775	.27	6.60
Lyons	2,071	575	3.6	...	200,000	96.5	No.	.50	...	528	.25	10.00
Pratt	3,302	650	5.1	100	250,000	76	Yes.	...	.125	551	.17	5.30
Scammon	2,233	364	6.1	2	140,000	63	No.	.50	.12	235	.11	7.80
Sterling	2,133	450	4.7	100	137,000	64	No.	...	.20	395	.19	8.80

TABLE VI—CONCLUDED.

City.	Population 1910.	Number of connections.	Population per connection.	Per cent of connections metered.	Consumption in gallons per day.	Consumption in gallons per day per capita.	Sewers.	Minimum monthly rate.	Rate per 1,000 gallons.	Tons of pipe.	Tons per capita.	Tons per fire hydrant.
CITIES OF MORE THAN 3000 AND LESS THAN 5000 POPULATION.												
Abilene	4,118	1,220	3.4	100	750,000	182	Yes.	$0.333	$0.25	1,562	.38	14.20
Beloit	3,082	650	4.8	100	275,000	89	Yes.	.416	.20	663	.22	6.10
Clay Center	3,438	725	4.7	99	350,000	102	Yes.	.416	.20	655	.19	11.20
Columbus	3,064	715	4.3	65	137,000	44.6	Yes.	.50	.20	675	.22	8.10
Concordia	4,415	700	6.3	100	300,000	68	Yes.	....	.15	932	.21	10.60
Dodge	3,214	849	3.8	40	500,000	155	Yes.	.50	.35	872	.27	11.50
El Dorado	3,129	480	6.5	95	300,000	96	Yes.	....	.25	796	.25	11.10
Frontenac	3,396	603	5.6	14	65,000	16	No.	.50	.50	251	.074	8.70
Garden City	3,171	400	7.9	90	500,000	16	No.	....	.10	528	.17	12.30
Great Bend	4,622	420	11	99	250,000	60	Yes.	1.25	.30	673	.15	9.00
Herington	3,273	230	14.2	100	....	....	Yes.	.50	.20	....	....	....
McPherson	3,546	790	4.5	97	34,500	98	Yes.	.55	.30	697	.20	9.70
CITIES OF MORE THAN 5000 AND LESS THAN 20,000 POPULATION.												
Arkansas City	7,508	1,517	5.0	25	557,386	74	Yes.	....	....	1,185	.16	6.20
Hutchinson	16,364	2,898	5.7	100	....	....	Yes.	$0.30	$0.30	2,884	.18	8.00
Junction City	5,598	1,332	4.2	99	621,400	111	Yes.	....	.15	1,246	.22	13.40
Lawrence	12,374	2,472	5.0	65	1,250,000	101	Yes.	62.5	.25	1,971	.16	11.40
Manhattan	5,722	1,561	3.7	88	400,000	70	Yes.	.58	.20	1,085	.19	11.60

Newton	7,862	2,120	3.7	....	1,170,150	149	Yes.	.70	.25	....	....	....
Pittsburg	14,755	3,965	3.7	25	1,250,000	85	Yes.	.80	.40	3,984	.27	15.00
Wellington	7,034	1,298	5.4	....	1,000,000	142	Yes.	.50	.15	923	.13	8.80
Salina	9,688	....	....	....	....	....	Yes.	....	....	....	....	....
CITIES OF MORE THAN 20,000 POPULATION.												
Topeka	43,684	7,000	6.2	100	2,831,500	65	Yes.	$0.40	$0.35	7,912	.18	13.00
Wichita	52,450	7,600	6.9	50	3,550,000	68	Yes.	.75	.25	11,023	.21	16.30

ABILENE.

Population in 1910, 4770. Plant built in 1881. Rebuilt in 1890 by private company. Purchased by city in 1907. Source of supply, spring collected in well 30 feet deep and 30 feet in diameter. Water pumped by steam Worthington compound duplex, 1,250,000 gallons daily; motor-driven centrifugal, 800,000 gallons daily; motor-driven triplex, 650,000 gallons daily; Booster pump for fire pressure, motor-driven centrifugal, 172,500 gallons daily. Water is pumped to two standpipes 100 feet and 50 feet high. Current furnished by Western Electric Company. Distribution system: 6-inch, 4 miles; 4-inch, 6 miles. Fire hydrants, 110; rental, $27.25 each per year. Consumers, 1200; 100 per cent metered. Consumption, 750,000 to 1,000,000 gallons daily. Minimum rate, $1 per quarter, with sliding scale from 25 cents for first 10,000 gallons down to 5 cents per 1000 gallons.

WATER ANALYSIS.

Laboratory No. 4851. Source, sand springs; collected by T. S. Worley; analysis completed March 7, 1912.

Laboratory No. 5909. Source, tap; collected by K. Riddle; analysis completed August 8, 1913.

Bacterial Examination.	*4851*	*5909*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	105	....
Agar, at 37° —24 hrs	30	10
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	....
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	0	.2
Nitrogen as free ammonia	.102	.006
Nitrogen as alb. ammonia	.158	.014
Nitrogen as nitrites	0	0
Nitrogen as nitrates	1	1
Total solids	183	203
Mineral Analysis.		
SiO_2	15	22
$Fe_2O_3+Al_2O_3$	.4	1.2
Ca	49.4	40.5
Mg	9.05	9.8
Na+K	4	11
Cl	12	14
SO_4	16.2	40.7
HCO_3	162.8	156

Hardness group, 3; total solids group, 2.

ALMENA.

Population 1910, 702. Combined water and light plant built by city in 1907. Source of supply, two 10-inch wells 55 feet deep. Water pumped to 50,000-gallon elevated tank by 200 g. p. m. triplex pump, connected to either 30 hp. Muncie oil engine or 24 hp. Fairbanks-Morse gasoline engine. Distribution system: 6-inch, 8000 feet; 4-inch, 9000 feet; 2-inch, 2000 feet. Fire hydrants, 24; rental, none. Consumers, 90; 100 per cent metered. Minimum rate, 50 cents per month. Meters owned by city.

WATER ANALYSIS.

Laboratory No. 5557. Collected by A. Bennie; analysis completed January 31, 1913.

Laboratory No. 5878. Collected by L. Wold; analysis completed August 4, 1913.

Bacterial Examination.	*5557*	*5878*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	150	5
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	slightly yellow	0
Odor	0	0
Turbidity	slight	25
Oxygen consumed	1.4	1.2
Nitrogen as free ammonia	.166	.204
Nitrogen as alb. ammonia	.072	.012
Nitrogen as nitrites	.001	.0075
Nitrogen as nitrates	.1	0
Total solids	457	449
Mineral Analysis.		
SiO_2	48	57
$Fe_2O_3+Al_2O_3$	10.4	.6
Ca	99.5	70
Mg	20.9	28
Na+K	19.5	41
Cl	22	21
SO_4	26.3	22.9
HCO_3	388	400.5

Hardness group, 6; total solids group, 7.

ALTON.

Population in 1910, 414. Combined water and light plant. The source of supply to be from one well 10 feet in diameter, 50 feet in depth, with brick casing. There are to be two 50 hp. oil engines. There will be a deep-well triplex pump with a capacity of 175 gallons per minute, discharging into a 50,000-gallon tank on a 120-foot tower. There will be 4600 feet of 6-inch and 11,000 feet of 4-inch cast-iron pipe, with 29 fire hydrants.

WATER ANALYSIS.

Laboratory No. 6625. Source, P. C. S.; collected by Porter Brown; date of collection, May 15, 1914; analysis completed May 20, 1914.

Chemical Analysis. Results in parts per million.	*6625*	
Color	none	....
Odor	none	....
Turbidity	30	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	N. D.	....
Nitrogen as alb. ammonia	N. D.	....
Nitrogen as nitrites	none	....
Nitrogen as nitrates	none	....
Total solids	524	....
Mineral Analysis.		
Cl	32.2	....
SO_4	79.8	....
HCO_3	334.8	....

ALTOONA.

Population in 1910, 1700. Plant built by city in 1911. Source of supply, one well 20 feet in diameter, 33 feet deep, cased with brick. Water pumped to 70,000-gallon tank on 100-foot tower by 350 g. p. m. Smith-Vaile triplex pump, driven by Fairbanks-Morse gasoline engine. Distribution system: 8-inch, 40 feet; 6-inch, 7530 feet; 4-inch, 6436 feet; 2-inch, 600 feet. Fire hydrants, 14; rental, none. Consumers, 96; 9 per cent metered. Daily consumption, 30,000 to 100,000 gallons. Minimum rate, 50 cents per month, with sliding scale ranging from 35 to 17½ cents.

ANTHONY.

Population in 1910, 2669. Combined water and light plant was built by the city. Supply is taken from two wells 15 feet in diameter and 20 feet in depth, cased with cement blocks with open joints into 8 inches of sand and gravel. There is a receiving well 30 feet in diameter, 14 feet 3 inches in depth, with a cement floor and shingle roof. The wells are all located in the bed of a stream which is dry most of the time. The receiving well collects water by gravity from the other two. Water is pumped by an American centrifugal 370 g. p. m. pump, and a Gardner direct-acting 1000 g. p. m. pump, into a 150,000-gallon elevated tank, 110 feet high, covered. Distribution system: 3 miles of 10-inch, 1018 feet of 8-inch, 1830 feet of 6-inch, 29,678 feet of 4-inch, and 7000 feet of 2-inch pipe, part of it used in the water-collection system of vitrified tile. There are 75 fire hydrants and 400 consumers. Minimum rate charged for water is 15 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 6047. Source, fire plug; collected by Kirkpatrick; date of collection, September 15, 1913; analysis completed September 15, 1913.

Laboratory No. 6111. Source, house service; collected by Kirkpatrick; date of collection, October 7, 1913; analysis completed October 14, 1913.

Bacterial Examination.	*6047*	*6111*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	3,000	120
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	3+ 2—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.4	1.45
Nitrogen as free ammonia	.008	.03
Nitrogen as alb. ammonia	0	.028
Nitrogen as nitrites	.002	trace
Nitrogen as nitrates	.5	.7
Total solids	525	494
Mineral Analysis.		
SiO_2	22	22
$Fe_2O_3+Al_2O_3$	.6	2.8
Ca	62.7	84
Mg	10.6	23
Na+K	105	51
Cl	78	45
SO_4	141.5	174
HCO_3	205	158.5

Hardness group, 4; total solids group, 8.

ARKANSAS CITY.

Population in 1910, 7508. Plant built by city in 1885. Source of supply, two wells, Layne & Bowler type, with submerged centrifugal pumps driven by 20 hp. motors, discharging through an 18-inch cypress line 6516 feet long, to a reservoir underneath pumphouse. Wells are 24 inches in diameter, 42 feet deep. Water pumped to the city by two Blake compound duplex steam pumps, 750 g. p. m. each. Standpipe 125 feet high, with a capacity of 73,500 gallons, is situated on a high point. Distribution system: 10-inch, 2000 feet; 8-inch, 3200 feet; 6-inch, 20,500 feet; 4-inch, 63,200 feet; 2-inch, 2400 feet. Connections, 1516; 25 per cent metered. Fire hydrants, 183; rental, $18.37 per year each. Daily consumption, 557,380 gallons. Average rate, 15½ cents a thousand. At present Arkansas City is rebuilding the pumping station, with an installation of two high-duty steam pumps, extensive additions to the distribution system, and a new elevated tank and tower.

WATER ANALYSIS.

Laboratory No. 5089. Collected by Ingersoll; analysis completed August 3, 1912.

Laboratory No. 5979. Collected by Wickliff; analysis completed August 26, 1913.

Bacterial Examination.	*5089*	*5979*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	....	3
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	....	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	....	.90
Nitrogen as free ammonia	.02	.01
Nitrogen as alb. ammonia	.070	.036
Nitrogen as nitrites	.02	.01
Nitrogen as nitrates	3	2
Total solids	682	800
Mineral Analysis.		
SiO_2	6.6	22
$Fe_2O_3+Al_2O_3$	0	.04
Ca	109.4	116.9
Mg	18.4	20.3
Na+K	89.5	207
Cl	119	240
SO_4	144	158
HCO_3	249	268

Hardness group, 7; total solids group, 12-14.

ASHLAND.

Population in 1910, 910. Combined water and light plant was built by the city in 1910. Water is secured from four wells, 6 feet in diameter and 50 feet in depth cased with perforated wrought-iron pipe. Water is secured from 3 feet 6 inches of gravel underlying 9 feet of fine sand. Water is pumped by a Deane triplex 350 g. p. m. pump, under a head of 150 feet, into a 50,000-gallon covered, elevated tank. Power is furnished by two Fairbanks-Morse vertical 50 and 150 hp., respectively, oil engines. Distribution system: 750 feet of 8-inch; 3150 feet of 6-inch and 12,450 feet of 4-inch cast-iron pipe, with 21 fire hydrants.

WATER ANALYSIS.

Laboratory No. 5248. Collected by Wallingford; analysis completed September 28, 1912.

Laboratory No. 6235. Collected by Howes; analysis completed November 21, 1913.

Bacterial Examination.	*5248*	*6235*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37°—24 hrs.	500	24
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	1+ 2—	2+ 3—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	2—	....

Chemical Analysis.

Results in parts per million.

Color	c	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	1.2	1.7
Nitrogen as free ammonia	.026	.018
Nitrogen as alb. ammonia	.05	.076
Nitrogen as nitrites	trace	0
Nitrogen as nitrates	.5	.01
Total solids	761	901
Mineral Analysis.		
SiO_2	24	28
$Fe_2O_3+Al_2O_3$	6	2.4
Ca	151	131
Mg	53.7	60
Na+K	4	30
Cl	19	22
SO_4	387.6	387.6
HCO_3	220	254

Hardness group, 7; total solids group, 13-16.

ATTICA.

Population in 1910, 737. Combined waterworks and electric light plant under construction. Water will be pumped from a 16-foot well, 25 feet deep, to a fifty-thousand-gallon tank on a hundred-foot tower by a 250 g. p. m. motor-driven triplex pump. Distribution system: 8-inch, 2200; 6-inch, 3000; 4-inch, 11,000 feet; cast-iron pipe. Fire hydrants, 20. New supply 1915.

ATWOOD.

Population in 1910, 680. Plant built by city in 1906. Source of supply, one 4-inch and one 18-inch well, 32 feet deep. Water pumped to a 13,500-gallon compressed air tank by two Fairbanks-Morse 240 g. p. m. duplex pumps. Distribution system: 8-inch, 40 feet; 6-inch, 1435 feet; 4-inch, 5070 feet. Fire hydrants, 15; rental, $10 each per year. Consumers, 82; 75 per cent metered. Average consumption, 67,500 gallons daily. Minimum rate, 50 cents per month, with a sliding scale from 25 cents to 12½ cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5390. Source, pumping station; collected by E. Muller; analysis completed November 25, 1912.

Laboratory No. 5937. Collected by E. Muller; analysis completed August 13, 1913.

Bacterial Examination.	*5390*	*5937*
Bacteria per cc. on		
Gelatin, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	220	500
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	3+	5+
in five .1 cc. tubes	3+	5—

Chemical Analysis. Results in parts per million.		
Color	c	....
Oxygen consumed	....	.3
Nitrogen as free ammonia	....	.002
Nitrogen as alb. ammonia	.088	
Nitrogen as nitrites	.002	518
Nitrogen as nitrates	.3	....
Total solids	520	....
Mineral Analysis.		
SiO_2	40	....
$Fe_2O_3+Al_2O_3$	1.4	....
Ca	82.2	....
Mg	23	....
Na+K	75.5	....
Cl	19	23
SO_4	84	73.6
HCO_3	427.5	405

Hardness group, 6; total solids group, 8.

BALDWIN.

Population in 1910, 1386. Combined water and light plant built by city in 1908. Source of supply, well 40 feet in diameter, 28 feet deep, cased with brick, fed by infiltration galleries of 6-inch drain tile, laid in trenches 12 to 18 feet in depth, covered with 18 inches of sand, then 12 inches of chats, all arched over with filter brick. Trench reaches sandstone. Water pumped from well to pump house, thence to elevated tank. Pumps connected to 50 kw., A. C. generator, driven by 125 hp. Webber gas engine. Distribution system: 4-inch, 4000 feet; 2-inch, 3400 feet. Fire hydrants, 50; rental, $12 per year each. Consumers, 225; 100 per cent metered. Daily consumption, 35,000 to 60,000 gallons. Minimum rate 75 cents per month, with sliding scale from 27 cents to 15 cents per 100 cubic feet.

WATER ANALYSIS.

Laboratory No. 4843. Collected by Downs; analysis completed March 4, 1912.

Laboratory No. 6031. Collected by Downs; analysis completed September 12, 1913.

Bacterial Examination.	*4843*	*6031*
Bacteria per cc. on		
Gelatin, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	....	130
Presumptive tests for *B. coli*	....	+
Number of positive fermentations:		
in one 10 cc. tube	....	+
in five 1 cc. tubes	....	3+ 2—
Chemical Analysis. Results in parts per million.		
Color	....	0
Odor	....	0
Turbidity	18	0
Oxygen consumed	1.58	0
Nitrogen as free ammonia	.392	0
Nitrogen as alb. ammonia	.132	0
Nitrogen as nitrites	.04	.0005
Nitrogen as nitrates	1	.1
Total solids	102	136

Mineral Analysis.

SiO_2	....	20.2
$Fe_2O_3+Al_2O_3$	....	1.4
Ca	....	28
Mg	....	6.5
Na+K	....	8
Cl	0	8
SO_4	....	trace
HCO_3	92.1	126.9

Hardness group, 1; total solids group, 1.

BAXTER SPRINGS.

Population in 1910, 1598. Plant built in 1905 by Baxter Mineral Springs Water Company. Present ownership, Miss Miriam Brown. Source of supply, two wells 5⅝ inches in diameter, 1100 feet deep. Water secured from well by air lift pump, capacity 160 gallons per minute, driven by 8 hp. gas engine. Pumped to compression tank, capacity 20,000 gallons, by steam pump, capacity 250 gallons per minute. Distribution system: 3-inch, 1 mile; 2-inch, 4 miles; 1½-inch, ——. No fire hydrants. Consumers, 250; 20 per cent metered. Daily consumption, 20,000 to 40,000 gallons. Minimum rate, 50 cents.

WATER ANALYSIS.

Laboratory No. 5594. Collected by Doctor Jones; analysis completed February 20, 1913.

Laboratory No. 6345. Collected by M. D. Opperman; analysis completed January 20, 1914.

Bacterial Examination.	*5594*	*6345*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	400
Agar, at 37° —24 hrs.	30	500
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	c
Oxygen consumed	.9	.4
Nitrogen as free ammonia	.038	.078
Nitrogen as alb. ammonia	.018	.082
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	0	.4
Total solids	219	228

Mineral Analysis.

SiO_2	9.2	....
$Fe_2O_3+Al_2O_3$	1.4	....
Ca	38.8	....
Mg	17.9	....
Na+K	17	....
Cl	30	28
SO_4	13.3	14.2
HCO_3	186	187.8

Hardness group, 3; total solids group, 2.

BELLE PLAINE.

Population in 1910, 849. Combined water and light plant, built in 1913 by the city. Source of supply, one 15-inch and one 28-inch well. Depth, 41 feet; cased with patented cement casing. Water pumped to 50,000-gallon tank on a 100-foot tower, by a 150 g. p. m. motor-driven triplex pump or 250 g. p. m. motor-driven turbine. Distribution system: 8-inch, 1584 feet; 6-inch, 3480 feet; 4-inch, 13,260; 2-inch, 5530 feet. Fire hydrants, 32; no rental. Consumers, 110; 92 per cent metered. Daily consumption about 40,000 gallons. Minimum rate, 75 cents per month, with sliding scale.

WATER ANALYSIS.

Laboratory No. 6061. Collected by city; analysis completed September 21, 1913.

Laboratory No. 6486. Collected by V. E. Herbert; analysis completed March 3, 1914.

Bacterial Examination.	*6061*	*6486*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	10
Agar, at 37° —24 hrs.	170	20
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	5+	5—
in five .1 cc. tubes	1+ 4—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	c
Oxygen consumed	.8	.53
Nitrogen as free ammonia	.01	.006
Nitrogen as alb. ammonia	.088	.03
Nitrogen as nitrites	.005	0
Nitrogen as nitrates	3	.2
Total solids	209	184
Mineral Analysis.		
Cl	12	13
SO_4	12.34	12
HCO_3	136.6	151

Hardness group, 2; total solids group, 2.

BELLEVILLE.

Population in 1910, 2224. Combined water and light plant, built by city in 1892; rebuilt in 1912. Source of supply, three 8-inch wells 190 feet deep to Dakota sandstone, cased with steel. Water pumped by motor-driven pump on each well, with capacities of 35 and 40 gallons per minute, discharging to surface reservoir, capacity 60,000 gallons. From this is pumped by 350 g. p. m. centrifugal pump to standpipe, capacity 100,000 gallons, 110 feet in height. Prime mover, 170 hp. Diesel oil engine, 75 hp. auxiliary steam plant. Distribution system: 8-inch, 5280 feet; 6-inch, 15,804 feet; 4-inch, 10,560 feet. Fire hydrants, 48; no rental. Consumers, 458; 4 per cent metered. Daily consumption, 40,000 to 150,000 gallons. Rate, 90 cents per month for family use; 50 cents per thousand gallons; over 1000 gallons per day, 40 cents.

WATER ANALYSIS.

Laboratory No. 4951. Collected by Schaefer; analysis completed May 1, 1912.

Laboratory No. 5861. Collected by Schaefer; analysis completed July 29, 1913.

Bacterial Examination.	*4951*	*5861*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	110,000	....
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	1+ 1—	5+
in five .1 cc tubes	1+ 2—	....
in five .01 cc. tubes	3—	....

Chemical Analysis.
Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	20	0
Oxygen consumed	.18	1.15
Nitrogen as free ammonia	.018	....
Nitrogen as alb. ammonia	.058	.006
Nitrogen as nitrites	0	.001
Nitrogen as nitrates	.15	0
Total solids	682	780

Mineral Analysis.

SiO_2	5.6	12.6
$Fe_2O_3+Al_2O_3$	3.6	1.2
Ca	35.735	45
Mg	trace	15
Na+K	225.7	229
Cl	49.6	80.
SO_4	127	116.4
HCO_3	461	534.5

Hardness group, 9; total solids group, 14.

BELOIT.

Population in 1910, 3082. Combined water and light plant, rebuilt by city in 1908. Source of supply,* twelve 8-inch wells 44 feet deep. Water pumped by two 350 g. p. m. motor-driven triplex pumps to 100,000-gallon elevated tank on a 75-foot tower. Distribution system: 10-inch, 4000 feet; 8-inch, 4000 feet; 6-inch, 2000 feet; 4-inch, 37,500 feet of cast-iron pipe. Fire hydrants, 108; rental none. Consumers, 650; 100 per cent metered. Daily consumption, 150,000 to 400,000 gallons. Minimum rate for water, $5 per year, with sliding scale from 20 cents to 10 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5482. Source, hydrant; collected by Herrick; analysis completed January 7, 1913.

Laboratory No. 5972. Source, C. S.; collected by Water Co.; analysis completed August 28, 1913.

* Considering changing source of supply to Solomon river, with modern rapid sand filter.

Bacterial Examination.	*5482*	*5972*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	80	2,000
Presumptive tests for *B. coli*.	+	+
Number of positive fermentations:		
in one 10 cc. tube.	+	+
in five 1 cc. tubes.	1+ 2—	5+
in five .1 cc. tubes.	3—	3+ 2—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.3	.65
Nitrogen as free ammonia	.012	.008
Nitrogen as alb. ammonia	.044	.024
Nitrogen as nitrites	.001	0
Nitrogen as nitrates	.5	.8
Total solids	945	665
Mineral Analysis.		
SiO_2	25	25.4
$Fe_2O_3+Al_2O_3$	.75	2
Ca	192	99
Mg	12.8	12.8
Na+K	118.4	128
Cl	210	102
SO_4	132.7	92.95
HCO_3	432.5	414.8

Hardness group, 9; total solids group, 17.

BENNINGTON.

Population in 1910, 386. Plant built in 1913 by city. Source of supply, two 8-inch wells 50 feet deep. Water pumped by 180 g. p. m. motor-driven triplex pump to 50,000-gallon tank on 100-foot tower. Distribution system: 6-inch, 2850 feet; 4-inch, 10,100 feet of cast-iron pipe. Fire hydrants, 26; no rental. Consumers 23; all metered. Daily consumption, 2000 gallons. New plant.

WATER ANALYSIS.

Laboratory No. 6106. Source, C. S.; collected by city clerk; analysis completed October 14, 1913.

Bacterial Examination.	*6106*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	1,600	....
Presumptive tests for *B. coli*.	—	....
Number of positive fermentations:		
in one 10 cc. tube.	—	....
in five 1 cc. tubes.	5—	....
in five .1 cc. tubes.	5—	....

Chemical Analysis.

Results in parts per million.

Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	.2	....
Nitrogen as free ammonia	.016	....
Nitrogen as alb. ammonia	.008	....
Nitrogen as nitrites	.001	....
Nitrogen as nitrates	0	....
Total solids	208	....

Mineral Analysis.

SiO_2	26	....
$Fe_2O_3+Al_2O_3$	2	....
Ca	47	....
Mg	6	....
Na+K	13	....
Cl	8	....
SO_4	5.75	....
HCO_3	185.4	....

Hardness group, 2; total solids group, 2.

BLUE RAPIDS.

Population in 1910, 1730. Plant built by city in 1888; rebuilt in 1912. Source of supply, two wells 16 and 20 feet in diameter, 30 feet deep. Water pumped by Deane triplex 200 g. p. m. pump to reservoir on top of high hill, with capacity of 220,000 gallons. Pump driven either by electric motor or Stover gasoline engine. Distribution system: 6-inch, 6000 feet; 4-inch, 17,000 feet of cast-iron pipe. Fire hydrants, 25; no rental. Consumers, 230; 100 per cent metered. Daily consumption, 120,000 to 200,000 gallons. Minimum rate, 50 cents per month, with sliding scale from 25 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5207. Collected by Peacock; analysis completed October 9, 1912.

Laboratory No. 5915. Collected by Tibbits; analysis completed August 28, 1913.

*Bacterial Examination.**	*5207*	*5915*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	110	60
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	1+ 4—	2+ 3—
in five .1 cc. tubes	5—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.15	.64
Nitrogen as free ammonia	.044	.004
Nitrogen as alb. ammonia	.054	.006
Nitrogen as nitrites	0	.001
Nitrogen as nitrates	3	.7
Total solids	406	394

* Subsequent bacteriological analyses show great improvement.

Mineral Analysis.		
SiO_2	15.8	18.2
$Fe_2O_3+Al_2O_3$	3.0	1.2
Ca	81.5	37
Mg	38.8	23
Na+K	0	72
Cl	8	18
SO_4	45.6	45.2
HCO_3	365	330

Hardness group, 7; total solids group, 6.

BONNER SPRINGS.

Population in 1910, 1462. Plant built by city in 1908. Source of supply, four 8-inch wells and four 6-inch, both 37 feet deep. Water pumped by vertical triplex power pump, 300 gallons per minute. Driven by 50 hp. Olds gas engine into a 50,000-gallon standpipe 125 feet high. Distribution system: 8-inch, 450 feet; 6-inch, 5280 feet; 4-inch, 13,200 feet; 3-inch, 1600 feet; 2-inch, 2285 feet of cast-iron pipe. Fire hydrants, 35. No rental. Consumers, 138; all metered. Daily consumption, 50,000 to 70,000 gallons. Minimum rate, 50 cents per month. Rate for 1000 gallons, 30 cents. Sliding scale to 20 cents.

WATER ANALYSIS.

Laboratory No. 5391. Collected by F. E. Frame; analysis completed November 25, 1912.

Laboratory No. 6392. Collected by F. E. Frame; analysis completed February 3, 1914.

Bacterial Examination.	*5391*	*6392*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	100
Agar, at 37° —24 hrs	10	80
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	....	0
Odor	....	0
Turbidity	....	10
Oxygen consumed	0	1.8
Nitrogen as free ammonia	.034	.164
Nitrogen as alb. ammonia	.104	.052
Nitrogen as nitrites	.005	0
Nitrogen as nitrates	.2	.2
Total solids	409	486
Mineral Analysis.		
SiO_2	29.2	....
$Fe_2O_3+Al_2O_3$	1.0	....
Ca	117.2	....
Mg	12.6	....
Na+K	8	....
Cl	9.6	7
SO_4	34.5	24.9
HCO_3	381	361.5

Hardness group, 6; total solids group, 8.

BUCKLIN.

Population in 1910, 696. Plant built by city in 1913. Source of supply, well 6 feet in diameter, 104 feet deep, 16-inch hole drilled 21 feet further. Water pumped by Downie deep-well pump, 110 gallons per minute capacity, driven by motor from private electric light company. Water pumped to elevated tank, capacity 65,000 gallons, 100 feet high. Distribution system: 8-inch, 2505 feet; 6-inch, 3820 feet; 4-inch, 9680 feet of cast-iron pipe; 2-inch, 2610 feet. Fire hydrants, 23; no rental. Consumers, 115. All metered. Daily consumption, 10,000 to 60,000 gallons. Minimum rate, $1 per month.

WATER ANALYSIS.

Laboratory No. 5974. Collected by Gordon; analysis completed August 28, 1913.

Laboratory No. 6257. Collected by W. R. Gordon; analysis completed December 6, 1913.

Bacterial Examination.	*5974*	*6257*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	70	....
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	2+ 3—	5—
in five .1 cc. tubes	5—	....
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.20	.45
Nitrogen as free ammonia	.004	.082
Nitrogen as alb. ammonia	.006	.01
Nitrogen as nitrites	.002	trace
Nitrogen as nitrates	.5	2
Total solids	281	294
Mineral Analysis.		
SiO_2	31	....
$Fe_2O_3+Al_2O_3$	.14	....
Ca	54.8	....
Mg	14.6	....
Na+K	34	....
Cl	19	8
SO_4	32.39	20
HCO_3	259	246.5

Hardness group, 4; total solids group, 4.

BURRTON.

Population in 1910, 689. Plant built in 1915. Source of supply, two wells 12 inches in diameter by 40 feet deep. The water is pumped into a 50,000-gallon tank on a 120-foot tower by two 6 x 8-inch triplex pumps. Distribution system: 8-inch, 1400 feet; 6-inch, 1600 feet; 4-inch, 19,650 feet of cast-iron pipe; 2-inch galvanized-iron pipe, 2600 feet. Fire hydrants, 39. New supply 1915.

BUNKER HILL.

Population in 1910, 242. Plant built by city in 1886. Water is secured from a spring, collected in a well 20 ft. by 30 ft., two and one-half miles south of the city. Pumped into a 16 ft. by 20 ft. covered reservoir in the city by a Deane duplex pump. There are two and one-half miles of 4-inch pipe carrying water to the city, and about two miles of 2-inch pipe distributing water. The minimum rate charged for water is $1 per month. No meters.

WATER ANALYSIS.

Laboratory No. 5649. Collected by Sellen; analysis completed April 11, 1913.

Laboratory No. 6455. Collected by G. R. Kistler; analysis completed February 20, 1914.

Bacterial Examination.	*5649*	*6455*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	600
Agar, at 37° —24 hrs.	....	12
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	+
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	slight	0
Oxygen consumed	1.2	1.5
Nitrogen as free ammonia	.024	.016
Nitrogen as alb. ammonia	.068	.112
Nitrogen as nitrites	.003	trace
Nitrogen as nitrates	7.0	3.5
Total solids	491	530
Mineral Analysis.		
SiO_2	17.6	....
$Fe_2O_3+Al_2O_3$	3.2	....
Ca	84.8	....
Mg	10.1	....
Na+K	54	....
Cl	42	48
SO_4	74.9	107.37
HCO_3	239	300.5

Hardness group, 5; total solids group, 8.

BURDEN.

Population in 1910, 424. Plant built by city in 1911. Source of supply, 7 springs collected in concrete reservoir 30 x 150 x 5 feet deep. Water pumped by 100 g. p. m. triplex pump, driven by Fairbanks-Morse distillate oil engine to 50,000-gallon tank on 100-foot tower. Distribution system: 6-inch, 9900 feet; 4-inch, 9320 feet of cast-iron pipe; 2-inch, 1400 feet. Fire hydrants, 16; no rental. Consumers, 136; practically all metered. Daily consumption, 12,000 gallons. Minimum rate, 50 cents, with sliding scale from 27 cents down.

WATER ANALYSIS.

Laboratory No. 6088. Collected by Crawford; analysis completed October 5, 1913.
Laboratory No. 6192. Collected by Crawford; analysis completed October 30, 1913.

Bacterial Examination.	*6088*	*6192*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	1,000	60
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	5+	3+ 2—
in five .1 cc. tubes	5+	1+ 4—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.5	3.4
Nitrongen as free ammonia	.002	.012
Nitrogen as alb. ammonia	.026	.052
Nitrogen as nitrites	.002	.0005
Nitrogen as nitrates	3.5	3
Total solids	328	347
Mineral Analysis.		
SiO_2	11.6	....
$Fe_2O_3+Al_2O_3$	1	....
Ca	99	....
Mg	6.6	....
Na+K	0	....
Cl	5	6
SO_4	7.4	10
HCO_3	315	305

Hardness group, 5; total solids group, 5.

BURR OAK.

Population in 1910, 1132. Plant built by city in 1912. Source of supply, one well 18 feet in diameter, 60 feet deep, cased with brick. Water pumped by two 200 g. p. m. deep-well, triplex pumps, to 50,000-gallon tank on 100 foot tower. One pump driven by 20 hp. Otto gas engine, one driven by 20 hp. Fairbanks-Morse oil engine. Distribution system: 8-inch, 1200 feet; 6-inch, 4200 feet; 4-inch, 16,000 feet of cast-iron pipe; 5600 feet of 2-inch wrought iron. Fire hydrants, 32; no rental. Consumers, 88. All metered. Daily consumption, 25,000 gallons. Minimum rate, 50 cents per month, with sliding scale from 20 cents to 10 cents.

WATER ANALYSIS.

Laboratory No. 5877. Collected by Korb; analysis completed March 4. 1913.

Bacterial Examination.	*5877*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	50	....
Presumptive tests for *B. coli*	+	....
Number of positive fermentations:		
in one 10 cc. tube	+	....
in five 1 cc. tubes	1+ 4—	....
in five .1 cc. tubes	4—	....
Chemical Analysis. Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	50	....
Oxygen consumed	.85	....
Nitragen as free ammonia	.42	....
Nitrogen as alb. ammonia	.048	....
Nitrogen as nitrites	.004	....
Nitrogen as nitrates	.5	....
Total solids	939	....
Mineral Analysis.		
SiO_2	29.2	....
$Fe_2O_3+Al_2O_3$	.1ppm.	....
Ca	130	....
Mg	37	....
Na+K	117	....
Cl	16	....
SO_4	349.5	....
HCO_3	422.5	....

Hardness group, 9; total solids group, 17.

CALDWELL.

Population in 1910, 2205. Plant built originally by city. Rebuilt in 1914. Light plant in connection. Source of supply, one well 15 feet in diameter, 43 feet deep, with masonry casing. Water pumped by two compound steam pumps, 1500 gallons per minute each, into standpipe 18 x 100 feet. Additional source of supply temporarily from Bluff Creek. Water also pumped by one 4-stage motor-driven centrifugal pump, 500 gallons per minute. New well under construction 15 feet in diameter, 50 feet deep, to be pumped by 2-stage motor-driven centrifugal pump, discharging into old well. Distribution system, 10-inch and smaller, 46,200 feet of cast-iron pipe. Fire hydrants, 72; rental, $25 per year each. Consumers, 369; 99 per cent metered. Daily consumption, 400,000 to 700,000 gallons. About one-half used by railroad. Minimum rate 50 cents per month, with sliding scale from 20 cents to 12 cents.

WATER ANALYSIS.

Laboratory No. 5468. Collected by Griswald; analysis completed January 3, 1913.

Laboratory No. 5870. Collected by Baker; analysis completed August 1, 1913.

Bacterial Examination.	*5468*	*5870*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs..............	....	....
Agar, at 37°—24 hrs................	q	1,000
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	4+ 1—
in five .1 cc. tubes	3—	4—

Chemical Analysis.
Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	2.5	1.55
Nitrogen as free ammonia	.016	.004
Nitrogen as alb. ammonia	.11	.022
Nitrogen as nitrites	.002	.004
Nitrogen as nitrates	0	.5
Total solids	571	1,009

Mineral Analysis.

SiO_2	12.6	24.4
$Fe_2O_3+Al_2O_3$	2	.8
Ca	76.5	138
Mg	16.4	51
Na+K	127	139
Cl	72	82
SO_4	94.5	301.9
HCO_3	366.5	522

Hardness group, 5; total solids group, 9.

CAWKER CITY.

Population in 1910, 870. Combined water and light plant, built in 1910 by the city. Source of supply, one well 12 feet in diameter, 60 feet deep. Water pumped by 200 g. p. m., motor-driven triplex pump, to 50,000-gallon tank on 100-foot tower. Distribution system: 6-inch, 9120 feet; 4-inch 7550 feet; 2-inch, 4750 feet. Fire hydrants, 48. Consumers, 105; 90 per cent metered. Daily consumption, 65,000 to 150,000 gallons. Minimum rate, $1.50 per quarter.

WATER ANALYSIS.

Laboratory No. 5481. Collected by Power; analysis completed January 7, 1913.

Laboratory No. 6164. Collected by McKinley; analysis completed October 22, 1913.

Bacterial Examination.	*5481*	*6164*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs..............	....	....
Agar, at 37° —24 hrs.................	90	125
Presumptive tests for *B. coli*.............	—	+
Number of positive fermentations:		
in one 10 cc. tube....................	+	+
in five 1 cc. tubes....................	3—	3+ 2—
in five .1 cc. tubes....................	3—	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.7	2.1
Nitrogen as free ammonia	.006	.012
Nitrogen as alb. ammonia	.04	.1
Nitrogen as nitrites	0	0
Nitrogen as nitrates	2	1
Total solids	421	409

Mineral Analysis.

SiO_2	43	21.8
$Fe_2O_3+Al_2O_3$	5	trace
Ca	102	88.8
Mg	9.23	11.5
Na+K	19.1	33
Cl	14	12
SO_4	37.4	32.91
HCO_3	337.2	352

Hardness group, 5; total solids group, 8.

CHAPMAN.

Population in 1910, 781. Plant built by city in 1912. Source of supply, three 10-inch wells 68 feet deep. Water pumped by 200 g. p. m. motor-driven triplex pump to 130,000-gallon standpipe 80 feet high. Distribution system: 10-inch, 1200 feet; 8-inch, 1200 feet; 6-inch, 6000 feet; 4-inch, 20,000 feet; 2-inch, 1400 feet. Fire hydrants, 30; no rental. Consumers, 68; all metered. Daily consumption, 10,000 gallons.

WATER ANALYSIS.

Laboratory No. 6218. Collected by A. C. Dietz; analysis completed November 8, 1913.

Laboratory No. 6448. Collected by A. C. Dietz; analysis completed February 21, 1914.

Bacterial Examination.	*6218*	*6448*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	liquid
Agar, at 37°—24 hrs.	....	85
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—

Chemical Analysis.

Results in parts per million.

Color	....	0
Odor	....	0
Turbidity	....	0
Oxygen consumed	2.2	2.1
Nitrogen as free ammonia	.068	0
Nitrogen as alb. ammonia	.022	.008
Nitrogen as nitrites	0	0
Nitrogen as nitrates	.1	1.5
Total solids	287	625

Mineral Analysis		
Cl	30	28
SO_4	131.2	181.8
HCO_3	309.9	310

Hardness group, 7; total solids group, 10.

CHEROKEE.

Population in 1910, 1452. Plant built by city in 1896. Source of supply, one well 6 inches in diameter, one 8 inches, 915 feet deep. Water raised to surface reservoir by Sullivan 2-stage compressor air lift, 250 gallons per minute, and Cooke deep-well pump, 100 gallons per minute. Reservoir has capacity of 270,000 gallons. Water pumped from reservoir to 50,000-gallon tank by compound duplex 350 g. p. m. steam pump. Distribution system, 8-inch, 800 feet; 6-inch, 700 feet; 4-inch, 2640 feet; 2-inch, 6800 feet. Fire hydrants, 34; rental none. Consumers, 327; 33⅓ per cent metered. Daily consumption, 115,000 gallons.

WATER ANALYSIS.

Laboratory No. 5579. Collected by C. Kelso; analysis completed February 21, 1913.

Laboratory No. 5953. Collected by R. A. Bolick; analysis completed July 26, 1913.

Bacterial Examination.	*5579*	*5953*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	....
Agar, at 37°—24 hrs	100	60
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	1+ 4—
in five .1 cc. tubes	5—	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	H_2S	H_2S
Turbidity	slight	0
Oxygen consumed	0	1.25
Nitrogen as free ammonia	.186	.142
Nitrogen as alb. ammonia	.066	.008
Nitrogen as nitrites	0	0
Nitrogen as nitrates	0	0
Total solids	555	534
Mineral Analysis.		
SiO_2	8.1	17.6
$Fe_2O_3+Al_2O_3$	2.8	.4
Ca	63.6	52
Mg	29.6	32.5
Na+K	93.9	99
Cl	83.2	90
SO_4	81.6	63.35
HCO_3	346	349

Hardness group, 5; total solids group, 9.

CHETOPA.

Population in 1910, 1548. Combined water and light plant built by city in 1905. Source of supply, one 8-inch well 1102 feet deep. Water pumped by Gardner 10 x 10 x 12 air compressor into concrete surface reservoir for aëration; thence by 2 Deane 350 g. p. m. steam pumps against direct pressure. Distribution system: 8-inch, 1800 feet; 6-inch, 3800 feet; 4-inch, 5900 feet; 2-inch, 4000 feet. Fire hydrants, 26; no rental. Consumers, 250; 10 per cent metered. Minimum rate 50 cents per month, with a sliding scale.

WATER ANALYSIS.

Laboratory No. 4903. Collected by A. R. Bell; analysis completed April 15, 1912.

Laboratory No. 5911. Collected by A. R. Bell; analysis completed August 8, 1913.

Bacterial Examination.	*4903*	*5911*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37° —24 hrs.	....	30
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—
in five .01 cc. tubes	....	2—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	H_2S
Turbidity	5	0
Oxygen consumed	1.71	1.1
Nitrogen as free ammonia	.38	.182
Nitrogen as alb. ammonia	.092	....
Nitrogen as nitrites	0	.002
Nitrogen as nitrates	0	.1
Total solids	786	810
Mineral Analysis.		
SiO_2	11.6	17.8
$Fe_2O_3+Al_2O_3$	2.2	2
Ca	6.8	7.6
Mg	28	3.8
Na+K	306	310
Cl	228.6	226
SO_4	0	11.5
HCO_3	464	454.5

Hardness group, 5; total solids group, 14.

CIMARRON.

Population in 1910, 587. Present plant built by city in 1913. Source of supply, two wells 8 inches in diameter, 160 feet deep. Pumped by two triplex pumps, 250 gallons per minute, into elevated tank, capacity 60,000 gallons, constructed of wood. Pumps driven by 60 hp. Muncie oil engine. Distribution system: 6-inch, 2830 feet; 4-inch, 8035 feet; 3½-inch, wrought iron, 5380 feet; 6-inch, wrought iron, 2080 feet. Fire hydrants, 23; no rental. Consumers, 40; all metered. Minimum rate, 15 cents per month.

WATER ANALYSIS.

Laboratory No. 7084. Collected by F. T. Hatch; analysis completed October 24, 1914.

Bacterial Examination.	*7084*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	15	....
Agar, at 37° —24 hrs.	3	....
Presumptive tests for *B. coli*.	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	0	....
Nitrogen as free ammonia	.052	....
Nitrogen as alb. ammonia	.068	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	0	....
Total solids	844	....
Mineral Analysis.		
SO_4	343.9	....
HCO_3	244	....

Hardness group, —; total solids group, 15.

CLAY CENTER.

Population in 1910, 3800. Combined water and light plant, built in 1885 by a private company, bought by the city about 1894. Source of supply, five wells—four 6-inch drilled wells and one 25-foot dug well, all about 35 feet deep. Water found in 12-foot layer of coarse gravel. Prime movers, two tandem high-speed engines and three return tubular boilers. Water pumped direct to distribution system by one 725 g. p. m. crank and fly-wheel cross-compound pump, and one 700 g. p. m. compound duplex pump, make unknown, against 250-foot head. No stand tower. Distribution system: 10-inch, 750 feet; 8-inch, 8500 feet; 6-inch, 14,900 feet; 4-inch, 16,600 feet; 2-inch, 23,800 feet. Fire hydrants, 58; rental, $45 each. Consumers, 725; 99 per cent metered. Average daily consumption, 350,000 gallons. Minimum rate, $5 per year. Rate per 1000 gallons, 20 cents.

WATER ANALYSIS.

Laboratory No. 5442. Collected by Basmussen; analysis completed December 11, 1912.

Laboratory No. 6046. Collected by E. R. DeBray; analysis completed September 15, 1913.

Bacterial Examination.	*5442*	*6046*
Bacteria per cc. on		
Gelatine, at 20° — 48 hrs.	....	....
Agar, at 37° —24 hrs.	50	10
Presumptive tests for *B. coli*.	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.
Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.9	.7
Nitrogen as free ammonia	.016	.006
Nitrogen as alb. ammonia	.042	0
Nitrogen as nitrites	.003	.003
Nitrogen as nitrates	3	.7
Total solids	973	1,008

Mineral Analysis.

SiO_2	38.6	....
$Fe_2O_3+Al_2O_3$	3.4	....
Ca	203	....
Mg	37.9	....
Na+K	34	....
Cl	28.8	32
SO_4	395	395
HCO_3	347	354

Hardness group, 13; total solids group, 19.

CLEARWATER.

Population in 1910, 569. Combined water and light plant constructed by city in 1912. Source of supply, two wells 12 inches in diameter and 50 feet deep. Water pumped by a 150 g. p. m. triplex pump, or 250 g. p. m. centrifugal pump into 50,000-gallon elevated tank on 100-foot tower. Pumps driven by Sheffield 60 hp. Solar oil engine and Columbus 25 hp. engine. Distribution system ———. Fire hydrants, 26; no rental. Consumers, 60; all metered. Daily consumption, 25,000 gallons. Minimum rate $1 per month, with sliding scale from 20 cents down.

WATER ANALYSIS.

Laboratory No. 6103. Collected by city clerk; analysis completed October 11, 1913.

Bacterial Examination.	*6103*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	160	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.
Results in parts per million.

Color	0	....
Odor	0	....
Turbidity	0	....
Nitrogen as free ammonia	.008	....
Nitrogen as alb. ammonia	.044	....
Nitrogen as nitrites	.0075	....
Nitrogen as nitrates	2	....
Total solids	489	....

Mineral Analysis		
Cl	14	....
SO_4	46.49	....
HCO_3	220	....

Hardness group, 4; total solids group, 8.

CLIFTON.

Population in 1910, 614. Plant built by city in 1903. Source of supply, one 16-foot well, 65 feet deep; one 20-foot well, 38 feet deep, cased with brick and stone. Water pumped by either of two Fairbanks-Morse 150 g. p. m. gasoline engines to a standpipe 12 x 100 feet. Distribution system, 8-inch, 500 feet; 6-inch, 2000 feet; 4-inch, 7500 feet; 2-inch, 700 feet; 1½-inch, 1000 feet. Fire hydrants, 28; no rental. Consumers, 130; one-half of one per cent metered. Daily consumption, 60,000 gallons. Flat rate of $5 per year for family use. Sliding scale 20 cents to 10 cents per thousand gallons. Mo. Pacific railroad purchases 450,000 gallons per month at 10 cents.

WATER ANALYSIS.

Laboratory No. 5523. Collected by Rush; analysis completed January 21, 1912.

Laboratory No. 6188. Collected by I. C. Rush; analysis completed October 30, 1913.

Bacterial Examination.	*5523*	*6188*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	1,500	3
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.9	2.4
Nitrogen as free ammonia	.054	.024
Nitrogen as alb. ammonia	.036	.082
Nitrogen as nitrites	.001	.005
Nitrogen as nitrates	3	2.5
Total solids	341	405
Mineral Analysis.		
SiO_2	19.8	25.4
$Fe_2O_3+Al_2O_3$	1.4	trace
Ca	69.2	74
Mg	7.86	14.7
Na+K	28.55	50
Cl	22	26
SO_4	28.3	89.7
HCO_3	251.5	273.5

Hardness group, 4; total solids group, 5.

CLYDE.

Population in 1910, 1057. Plant built in 1887 by the city. Originally water was taken from shallow wells on the bank of Elk creek. Supply is now taken from two wells 6 inches in diameter, 112 feet deep on the bank of Elk creek.

WATER ANALYSIS.

Laboratory No. 5539. Collected by Peterson; analysis completed January 22, 1913.

Laboratory No. 5922. Collected by C. E. Murphy; analysis completed August 14, 1913.

Bacterial Examination.	*5539*	*5922*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37° —24 hrs.	....	5
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	....	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	....
Odor	0	....
Turbidity	slight	....
Oxygen consumed	.6	.5
Nitrogen as free ammonia	.036	.008
Nitrogen as alb. ammonia	.008	....
Nitrogen as nitrites	0	.003
Nitrogen as nitrates	0	.1
Total solids	390	378
Mineral Analysis.		
SiO_2	18.8	24.5
$Fe_2O_3+Al_2O_3$	2.8	1.6
Ca	90	70
Mg	11.05	12.00
Na+K	31	64
Cl	22	24
SO_4	40	60
HCO_3	322.5	327.5

Hardness group, 5; total solids group, 6.

COLBY.

Population in 1910, 1130. Combined water and light plant constructed by city in 1910. Source of supply, two wells 10 inches in diameter, 140 feet deep. Water pumped by one Cook steam pump 100 g. p. m. capacity, driven by Skinner gas engine, and one Samson motor driven, 70 g. p. m. capacity deep-well pump, to 70,000-gallon tank on 100-foot tower. Distribution system: 10-inch, 950 feet; 8-inch, 4360 feet; 6-inch, 3520 feet; 4-inch, 21,290 feet; 2-inch, 1200 feet. Fire hydrants, 47; no rental. Consumers, 180; all metered. Daily consumption, 35,000 gallons. Minimum rate, 50 cents per month, with sliding scale from 25 cents to 12½ cents per thousand.

WATER ANALYSIS.

Laboratory No. 5307. Collected by C. A. Haskins; analysis completed October 19, 1912.

Laboratory No. 6133. Collected by Parrott; analysis completed October 15, 1913.

Bacterial Examination.	*5307*	*6133*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	120	25
Presumptive tests for B. *coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	0
Nitrogen as free ammonia	.016	0
Nitrogen as alb. ammonia	.02	.028
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	2	1
Total solids	310	306
Mineral Analysis.		
SiO_2	41.2	38
$Fe_2O_3+Al_2O_3$	2.4	2.6
Ca	49.9	45
Mg	16.7	15.8
Na+K	18.09	31
Cl	9.6	10
SO_4	28.1	25.1
HCO_3	241	246.5

Hardness group, 3; total solids group, 4.

COLDWATER.

Population in 1910, 684. Combined water and light plant built by city in 1911. Source of supply, four wells, 6 inches in diameter, 70 feet deep. Water pumped by 350 g. p. m. triplex pump to 50,000-gallon tank on 100-foot tower. Pump driven by 80 hp. distillate oil engine. Distribution system: 8-inch, 1560 feet; 6-inch, 3065 feet; 4-inch, 11,024 feet; 2-inch, 7300 feet. Fire hydrants, 40; rental, $25 per year each. Consumers, 125; all metered. Daily consumption, 15,000 gallons. Minimum rate $1 per month, with sliding scale from 25 cents to 15 cents per thousand.

WATER ANALYSIS.

Laboratory No. 4825. Collected by Baker; analysis completed, February 26, 1912.

Laboratory No. 6127. Collected by Baldwin; analysis completed October 15, 1913.

Bacterial Examination.	*4825*	*6127*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	....	....
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—

Chemical Analysis. Results in parts per million.		
Oxygen consumed	1.15	2.5
Nitrogen as free ammonia	.05	.004
Nitrogen as alb. ammonia	.024	.024
Nitrogen as nitrites	....	trace
Nitrogen as nitrates	1	.5
Total solids	122	178

Mineral Analysis		
SiO_2	....	14
$Fe_2O_3+Al_2O_3$	....	.04
Ca	....	50
Mg	....	2
Na+K	....	81
Cl	9	4
SO_4	trace	118.9
HCO_3	177.39	165.8

Hardness group, 3; total solids group, 2.

COLUMBUS.

Population in 1910, 3064. Plant built in 1887 by the city. Source of supply, two wells 8 inches in diameter, one 900 and one 1200 feet deep. Water pumped by two 200 g. p. m. deep-well steam pumps to surface aëration reservoir by 250 g. p. m. Buffalo steam pump, to 127,000-gallon standpipe 150 feet in height. Distribution system: 8-inch, 2350 feet; 6-inch, 22,500 feet; 4-inch, 22,600 feet; 3-inch, 600 feet; 2-inch, 1100 feet. Fire hydrants, 83; no rental. Consumers, 715; 65 per cent metered. Consumption, 150,000 gallons daily. Minimum rate, 50 cents. Rate for 1000 gallons, 20 cents.

WATER ANALYSIS.

Laboratory No. 4984. Collected by Hawkins; analysis completed June 17, 1912.

Laboratory No. 5967. Collected by Hawkins; analysis completed August 23, 1913.

Bacterial Examination.	*4984*	*5967*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	....
Agar, at 37° —24 hrs	....	8
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	c	sulphur
Oxygen consumed	.285	0
Nitrogen as free ammonia	.262	.270
Nitrogen as alb. ammonia	.076	.016
Nitrogen as nitrites	trace	0
Nitrogen as nitrates	.5	0
Total solids	347	457
Mineral Analysis.		
SiO_2	4	15
$Fe_2O_3+Al_2O_3$	0	1
Ca	49	50
Mg	24.55	31.5
Na+K	96	83
Cl	53	70
SO_4	52.2	34.14
HCO_3	369	366.5

Hardness group, 4; total solids group, 7.

CONCORDIA.

Population in 1910, 4415. Plant built by city in 1886. Rebuilt in 1911. Source of supply, twelve wells 6 inches in diameter, 48 feet deep. Water pumped by two motor-driven triplex pumps and one motor-driven centrifugal pump, discharging to stand pipe, with capacity of 260,000 gallons, 100 feet high. Pumps owned and operated by a private light company under contract for 2¾ cents per thousand gallons. Distribution system: 14-inch, 150 feet; 12-inch, 872 feet; 10-inch, 3276 feet; 8-inch, 8624 feet; 6-inch, 17,136 feet; 4-inch, 2252 feet. Fire hydrants, 88; no rental. Consumers, 700; all metered. Daily consumption, 300,000 gallons. Minimum rate, $1.25 per thousand cubic feet.

NOTE.—An old steam plant is kept in reserve.

WATER ANALYSIS.

Laboratory No. 5380. Collected by H. Logue; analysis completed October 21, 1912.

Laboratory No. 5973. Collected by Lash; analysis completed August 28, 1913.

Bacterial Examination.	*5380*	*5973*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	200	150
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.7	.8
Nitrogen as free ammonia	.8	.94
Nitrogen as alb. ammonia	.142	.074
Nitrogen as nitrites	.002	.02
Nitrogen as nitrates	trace	....
Total solids	504	515
Mineral Analysis.		
SiO_2	31.8	44.4
$Fe_2O_3+Al_2O_3$	1.8	7.2
Ca	96.9	94
Mg	15.9	16.6
Na+K	57.8	59
Cl	54.8	60
SO_4	53.3	49.8
HCO_3	364	361.5

Hardness group, 6; total solids group, 8.

CONWAY SPRINGS.

Population in 1910, 1292. Plant constructed in 1910 by J. M. Frantz. Source of supply, 8 wells, 12 inches in diameter, 40 feet deep. Cement tile casing. Water pumped by two 500 g. p. m. triplex pumps, driven by two Olds gas engines, 18 hp., and 10 hp. 3-phase electric motor. Pumps discharge to 70,000-gallon standpipe, 110 feet high. Distribution system: 6-inch, 5500 feet; 4-inch, 4000 feet; 2-inch, 2000 feet. Fire hydrants, 13; rental not specified. Consumers, 160; all metered. Daily consumption, 80,000 gallons. Minimum rate, $1 allowing 300 cu. ft. Above that, 15 cents per 100 cu. ft.

WATER ANALYSIS.

Laboratory No. 5415. Collected by E. J. Frantz; analysis completed November 26, 1912.

Laboratory No. 6247. Collected by Shelter; analysis completed November 26, 1913.

Bacterial Examination.	*5415*	*6247*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37°—24 hrs.	100	6
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	1+ 2—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.9	0
Nitrogen as free ammonia	.024	.012
Nitrogen as alb. ammonia	.014	.076
Nitrogen as nitrites	.001	0
Nitrogen as nitrates	6	4
Total solids	134	124

Mineral Analysis.		
SiO_2	25.4	....
$Fe_2O_3+Al_2O_3$	1	....
Ca	13.5	....
Mg	3.1	....
Na+K	6	....
Cl	3.0	8
SO_4	5.76	4.1
HCO_3	53.7	92.7

Hardness group, 1; total solids group, 1.

COTTONWOOD FALLS.

Population in 1910, 899. The original source of supply was from a series of springs two miles southwest of the city, but in 1912 it was changed to a well in the valley of the Cottonwood river, 20 feet in diameter and 20 feet in depth. Water was pumped by a private concern. In 1913, on account of lack of water, the city was taking water from the Cottonwood river and since that time a part has been secured from it. At the present time plans are under way for purchasing water from the city of Strong City. At present the water is pumped by a duplex motor-driven pump, with a capacity of 70 gallons per minute, against a head of 125 feet, into a standpipe 20 feet in diameter and 65 feet in height, on a neighboring hill. The standpipe has a capacity of 150,000 gallons. Distribution system consists of 3500 feet of 4-inch, 6-inch, and 8-inch pipe.

DELPHOS.

Population in 1910, 767. Plant was built in 1909 by the city. Water is secured from one well 20 feet in diameter and 25 feet deep, cased with brick. Water is pumped into a 50,000-gallon tank on a 100-foot tower by 350 g. p. m. Smith-Vaile, double-acting triplex pump. There are 2120 feet of 8-inch, 450 feet of 6-inch, and 16,767 feet of 4-inch cast-iron pipe, with 27 fire hydrants.

WATER ANALYSIS.

Laboratory No. 6079. Collected by city clerk; analysis completed September 30, 1913.

Laboratory No. 7007. Collected by B. R. Moore; analysis completed September 18, 1914.

Bacterial Examination.	*6079*	*7007*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	....
Agar, at 37° —24 hrs	140	3
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	3—

Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.5	0
Nitrogen as free ammonia	.008	.022
Nitrogen as alb. ammonia	.008	.108
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	....	0
Total solids	414	380
Mineral Analysis.		
SiO_2	33.4	....
$Fe_2O_3+Al_2O_3$	2	....
Ca	93	....
Mg	10.4	....
Na+K	23	....
Cl	18	24
SO_4	30.44	19.7
HCO_3	327.5	329.4

Hardness group, 5; total solids group, 6.

DODGE CITY.

Population in 1910, 3214. Plant built in 1886 by Midland Water, Light & Ice Co. Purchased by city in 1910. Source of supply, three 20-inch wells 25 feet deep, one 25-foot well 18 feet deep. Water pumped by crank and fly wheel 1000 g. p. m. steam pump and Underwriters compound duplex 1000 g. p. m. steam pump into 175,000-gallon standpipe. Distribution system: 14-inch, 300 feet; 12-inch, 325 feet; 10-inch, 1500 feet; 8-inch, 6975 feet; 6-inch, 18,575 feet; 4-inch, 3075 feet. Fire hydrants, 76; no rental. Consumers, 849; 40 per cent metered. Daily consumption, 200,000 to 1,500,000 gallons. Minimum rate, domestic 50 cents per month, business $1 per month, with sliding scale from 35 cents to 10 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5309. Collected by W. Matson; analysis completed November 12, 1912.

Laboratory No. 5998. Collected by Ballagher; analysis completed September 3, 1913.

Bacterial Examination.	*5309*	*5998*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	15	100
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1	1
Nitrogen as free ammonia	.01	.004
Nitrogen as alb. ammonia	.036	.002
Nitrogen as nitrites	.003	....
Nitrogen as nitrates	1.5	.5
Total solids	350	346
Mineral Analysis.		
SiO_2	27.4	57
$Fe_2O_3+Al_2O_3$	2.2	.14
Ca	62.2	43.2
Mg	21.7	26
Na+K	11.7	24
Cl	18	18
SO_4	56.9	58.4
HCO_3	227	220

Hardness group, 4; total solids group, 5.

DOWNS.

Population in 1910, 1427. Plant built by city in 1888. Source of supply, twelve 10-inch wells 57 to 64 feet in depth. Water pumped by Fairbanks-Morse gasoline engine and pump, 150 g. p. m. capacity, into stand pipe 12 x 115 feet, or Deane motor-driven pump 320 g. p. m. capacity. Distribution system: 6-inch, 3960 feet; 4-inch, 21,120 feet; 2-inch, 5000 feet. Fire hydrants, 31. Consumers, 250; metered. Daily consumption 100,000 gallons. Minimum rate 20 cents per thousand. Deane pump and motor installed in 1914, with six wells.

WATER ANALYSIS.

Laboratory No. 5392. Collected by L. R. Krohn; analysis completed October 16, 1912.

Laboratory No. 6386. Collected by F. R. Hesser; analysis completed December 18, 1913.

Bacterial Examination.	*5392*	*6386*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	100	5,000
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	.7
Nitrogen as free ammonia	.01	.04
Nitrogen as alb. ammonia	.026	.09
Nitrogen as nitrites	0	.003
Nitrogen as nitrates	.7	1.0
Total solids	522	532

Mineral Analysis.		
SiO_2	33.2	31.6
$Fe_2O_3+Al_2O_3$	1.2	2
Ca	122.7	120.6
Mg	10.25	14.2
Na+K	44	33
Cl	28	28
SO_4	95.7	96.6
HCO_3	361.5	352

Hardness group, 7; total solids group, 9.

EL DORADO.

Population in 1910, 3129. Plant built by private company in 1887, purchased by city in 1906. Source of supply, four wells, two 30 feet in diameter, one 15 inches in diameter, one infiltration reservoir, 23 x 90 feet, all ranging from 21 to 30 feet in depth. Also, 1220 feet of 4 x 6 infiltration tunnels. Water pumped by Fairbanks-Morse 350 g. p. m. or Fairbanks-Morse 500 g. p. m. pump to 125,000-gallon elevated tank on 100-foot tower. Distribution system: 12-inch, 500 feet; 10-inch, 2000 feet; 8-inch, 6500 feet; 6-inch, 4000 feet; 4-inch, 45,200 feet; 2-inch, 800 feet. Fire hydrants, 72; no rental. Consumers, 480; 95 per cent metered. Consumption, 300,000 gallons daily. Rate 8 cents to 25 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5236. Collected by W. H. Betz; analysis completed October 2, 1912.

Laboratory No. 5866. Collected by W. H. Betz; analysis completed July 30, 1913.

Bacterial Examination.	*5236*	*5866*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37°—24 hrs.	1,000	1,400
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	1+ 4—	4+ 1—
in five .1 cc. tubes	3—	1+ 4—
in five .01 cc. tubes	2—	....

Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	.8	1.40
Nitrogen as free ammonia	.018	.004
Nitrogen as alb. ammonia	.038	.044
Nitrogen as nitrites	0	.005
Nitrogen as nitrates	0	2.5
Total solids	354	596

Mineral Analysis.		
SiO_2	25.4	30
$Fe_2O_3+Al_2O_3$	5.8	1
Ca	113.4	60
Mg	9.6	16.8
Na+K	0	92
Cl	10	20
SO_4	17.1	68.71
HCO_3	339	386

Hardness group, 6; total solids group, 10.

ELLINWOOD.

Population in 1910, 976. Combined water and light plant built by city in 1909. Two 8-inch wells 145 feet deep furnish the supply. Water pumped by vertical deep well, 80 g. p. m. pump to 50,000-gallon tank on 100-foot tower. Also, 2-stage, 400 g. p. m. motor-driven centrifugal pump is available for fire pressure. A 10 hp. steam engine is available. Distribution system: 8-inch, 1750 feet; 6-inch, 1920 feet; 4-inch, 13,400 feet; 2-inch, 2500 feet. Fire hydrants, 22; $45.50 per year each for rental Consumers, 95; all metered. Daily consumption, 20,000 gallons. Minimum rate 75 cents per month.

WATER ANALYSIS.

Laboratory No. 4852. Collected by R. K. Hagler; analysis completed March 9, 1912.

Laboratory No. 6113. Collected by R. K. Hagler; analysis completed October 14, 1913.

Bacterial Examination.	*4852*	*6113*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	....	80
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	—	1+ 4—
in five .1 cc. tubes	—	5—

Chemical Analysis.

Results in parts per million.

Oxygen consumed	....	.4
Nitrogen as free ammonia	....	.03
Nitrogen as alb. ammonia	....	.154
Nitrogen as nitrites	....	trace
Nitrogen as nitrates	.4	....
Total solids	687	798

Mineral Analysis.		
SiO_2	12.4	17.6
$Fe_2O_3+Al_2O_3$	.2	1
Ca	100.53	114
Mg	24.81	10
Na+K	92	79
Cl	74	12
SO_4	271	303.5
HCO_3	198	207.5

Hardness group, 5; total solids group, 14.

ELLIS.

Population in 1910, 1404. Combined water and light plant built by city in 1909. Source of supply, one well 5 feet in diameter and 28 feet deep, cased with brick, into 8 feet of sand and gravel. The power is supplied by a 200 hp. Corliss steam engine, using oil for fuel. Water is pumped by a 200 g. p. m. triplex pump against a head of 175 feet. Distribution system consists of 5000 feet of 6-inch and 8000 feet of 4-inch cast-iron pipe. There are 44 fire hydrants for which the city pays $30 per year. There are 115 consumers, 95 domestic and 20 business, all metered. The daily consumption is in the neighborhood of 70,000 gallons. Minimum rate charged for water is $1 per month. Rate for 1000 gallons is 15 cents.

WATER ANALYSIS.

Laboratory No. 4889. Collected by D. C. Watkins; analysis completed April 12, 1912.

Laboratory No. 6051. Collected by R. T. Payne; analysis completed September 19, 1913.

Bacterial Examination.	*4889*	*6051*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	800	....
Agar, at 37° —24 hrs.	20	3
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	green	0
Odor	....	0
Turbidity	150	0
Oxygen consumed	4	0
Nitrogen as free ammonia	1.450	.75
Nitrogen as alb. ammonia	.178	.01
Nitrogen as nitrites	....	.004
Nitrogen as nitrates	....	0
Total solids	353	373
Mineral Analysis.		
SiO_2	30.4	20
$Fe_2O_3+Al_2O_3$	11.4	1.2
Ca	77.7	78
Mg	13.27	14.6
Na+K	28	33
Cl	14	12
SO_4	39.35	51
HCO_3	304	312.5

Hardness group, 5; total solids group, 5.

ELLSWORTH.

Population in 1910, 2041. Plant constructed in 1886, by the city. Source of supply, one well 25 feet in diameter, 35 feet deep; one well 24 feet in diameter, 26 feet deep. Water pumped by Buffalo horizontal duplex 350 g. p. m. pump, and a Smith-Vaile horizontal duplex 350 g. p. m. pump, into a 120,000-gallon standpipe. Distribution system: 8-inch,

8227 feet; 6-inch, 2832 feet; 4-inch, 17,177 feet; 2-inch, 672 feet. Fire hydrants, 65; no rental. Consumers, 321; all metered. Daily consumption, 51,000 gallons. Minimum charge, 50 cents per month.

WATER ANALYSIS.

Laboratory No. 5529. Collected by F. S. Foster; analysis completed February 1, 1913.

Laboratory No. 6226. Collected by O'Donnell; analysis completed November 17, 1913.

Bacterial Examination.	*5529*	*6226*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	60	17
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	c	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	2.1	1.5
Nitrogen as free ammonia	.044	.078
Nitrogen as alb. ammonia	.042	.064
Nitrogen as nitrites	.001	....
Nitrogen as nitrates	....	.1
Total solids	1,126	1,155
Mineral Analysis.		
SiO_2	24.8	42
$Fe_2O_3+Al_2O_3$	1.2	.3
Ca	208	126.4
Mg	18.2	21.2
Na+K	128	188
Cl	256	258
SO_4	227	213.6
HCO_3	334.8	308

Hardness group, 11; total solids group, 19.

ENGLEWOOD.

Population in 1910, 518. Combined water and light plant built by the city in 1911. Source of supply, one well 20 feet in diameter, 31 feet 4 inches deep. Power is furnished by a 50 hp. oil engine, driving a 35 K. W. generator. The water is pumped by a triplex 350 g. p. m. pump against a 200-foot head, into a 50,000-gallon covered tank on a 100-foot tower. The distribution system consists of 900 feet of 8-inch; 3330 feet of 6-inch; 5250 feet of 4-inch cast iron pipe. There are 18 fire hydrants.

WATER ANALYSIS.

Laboratory No. 7045. Collected by E. Martell; date of collection October 3, 1914; analysis completed October 8, 1914.

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Bacterial Examination.	*7045*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	300	....
Presumptive tests for *B. coli*	+	....
Number of positive fermentations:		
in one 10 cc. tube	1+	....
in five 1 cc. tubes	1+ 4—	....
Chemical Analysis. Results in parts per million.		
Color	none	....
Odor	none	....
Turbidity	none	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	.012	....
Nitrogen as alb. ammonia	.068	....
Nitrogen as nitrites	none	....
Nitrogen as nitrates	none	....
Total solids	461	....
Mineral Analysis.		
Cl	34	....
SO_4	46.5	....
HCO_3	320	....

ENTERPRISE.

Population in 1910, 706. Plant built by city in 1889. Source of supply, two 6-inch wells 43 feet deep. Water pumped by a Deane triplex 300 g. p. m. pump (discarded at present), and by a triplex 400 g. p. m. pump into 50,000-gallon tank on a 90-foot tower. Distribution system: 6-inch, 5000 feet; 4-inch, 2950 feet; 3-inch, 1850 feet. Fire hydrants, 18; no rental. Consumers, 105; all metered. Daily consumption, 35,000 gallons. Minimum rate, $1.50 per quarter.

WATER ANALYSIS.

Laboratory No. 5550. Collected by J. R. Clark; analysis completed January 28, 1913.

Laboratory No. 6112. Collected by R. E. Corbin; analysis completed October 14, 1913.

Bacterial Examination.	*5550*	*6112*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	250
Agar, at 37°—24 hrs.	700	251
Presumptive test for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	2+ 3—
in five .1 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1	0
Nitrogen as free ammonia	.028	.012
Nitrogen as alb. ammonia	.04	.09
Nitrogen as nitrites	.002	trace
Nitrogen as nitrates	.5	1.5
Total solids	1.028	945

Mineral Analysis.		
SiO_2	18	17.6
$Fe_2O_3+Al_2O_3$	1.8	7.8
Ca	173	151
Mg	60	50.5
Na+K	57	99
Cl	88	76
SO_4	319	329.12
HCO_3	422.5	429.4

Hardness group, 13; total solids group 19.

ERIE.

Population in 1910, 1300. Combined water and light plant built in 1910 by the city. Source of supply, one 16-inch well, 40 feet deep. Water pumped by two horizontal compound duplex pumps, 300 g. p. m. capacity, each, into a standpipe 75,000-gallon capacity, 120 feet high. Distribution system: 8-inch, 2640 feet; 6-inch, 2640 feet; 4-inch, 15,840 feet; 2-inch, 3960 feet. Fire hydrants, 35; no rental. Consumers, 220; all metered. Average daily consumption, 75,000 gallons. Minimum rate for water 50 cents per month, with a sliding scale from 30 cents to 5 cents per thousand.

WATER ANALYSIS.

Laboratory No. 4860. Collected by Frogue; analysis completed March 21, 1912.

Laboratory No. 6289. Collected by W. T. Allen; analysis completed December 20, 1913.

Bacterial Examination.	*4860*	*6289*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	millions	....
Agar, at 37°—24 hrs	1,300	140
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	1+	5—
in five .1 cc. tubes	1+	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.93	4.75
Nitrogen as free ammonia	0	.03
Nitrogen as alb. ammonia	.126	.036
Nitrogen as nitrites	.02	.003
Nitrogen as nitrates	2	2
Total solids	882	1,226
Mineral Analysis.		
SiO_2	16.6	18.4
$Fe_2O_3+Al_2O_3$	1	1.4
Ca	203.6	217
Mg	31.7	33.5
Na+K	76.6	82
Cl	106.4	106
SO_4	320	383.2
HCO_3	388.5	376

Hardness group, 12; total solids group, 16-23.

ESBON.

Population in 1910, 347. Plant built in 1914 by the city. Source of supply, dug well 8 feet in diameter, 61½ feet deep, cased with brick. Water is pumped by a 250 g. p. m. triplex pump, driven by a gasoline engine or a motor to a 50,000-gallon tank on a 100-foot tower. Power is furnished by a 50 hp. and 125 hp. oil engine, to be used in connection with the electric-light plant. Distribution system: 8-inch, 1250 feet; 6-inch, 6300 feet; 4-inch, 8000 feet of cast-iron pipe.

WATER ANALYSIS.

Laboratory No. 7024. Source, well; collected by B. Chambers; date of collection, September 24, 1914.

Bacterial Examination.	*7024*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	2,500	....
Presumptive tests for *B. coli*	+	....
Number of positive fermentations:		
in one 10 cc. tube	1+	....
in five 1 cc. tubes	5+	....
in five .1 cc. tubes	1+ 4—	....
Chemical Analysis.		
Results in parts per million.		
Color	none	....
Odor	none	....
Turbidity	none	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	.004	....
Nitrogen as alb. ammonia	.112	....
Nitrogen as nitrites	none	....
Nitrogen as nitrates	1	....
Total solids	601	....
Mineral Analysis.		
Cl	14	....
SO_4	123.4	....
HCO_3	381	....

EUREKA.

Population in 1910, 2333. Plant built by city in 1888. Source of supply, two wells 20 feet in diameter, 21 feet deep. One hundred-foot tunnel 3 x 5 feet connects wells. Water pumped by two Dean compound duplex steam pumps, with a capacity of 350 gallons per minute, each, into a standpipe 18 x 50 feet. Distribution system: 1½ miles of 6-inch pipe and smaller. Fire hydrants, 65; no rental. Consumers, 500; all metered. Daily consumption, 150,000 gallons. Rate for 1000 gallons, 8 cents to 35 cents.

WATER ANALYSIS.

Laboratory No. 5693. Collected by J. P. Alter; analysis completed May 13, 1913.

Laboratory No. 6824. Collected by W. T. Grove; analysis completed July 15, 1914.

Bacterial Examination.	*5963*	*6824*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37° —24 hrs.	....	40
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	2+ 3—	4+ 1—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.5	.35
Nitrogen as free ammonia	.02	.028
Nitrogen as alb. ammonia	.038	.052
Nitrogen as nitrites	.0075	.002
Nitrogen as nitrates	.3	1
Total solids	307	368
Mineral Analysis.		
SiO_2	11.2	....
$Fe_2O_3+Al_2O_3$	5	....
Ca	82.6	....
Mg	13.9	....
Na+K	12	....
Cl	16	28
SO_4	33.1	0
HCO_3	283	356.5

Hardness group, 5; total solids group, 5.

FLORENCE.

Population in 1910, 1168. Plant built in 1887 by the Florence Water Works Co. Water is secured from one well 45 feet in diameter, and 40 feet deep, with a gallery under the Cottonwood river. It is pumped by two Deane Compound duplex steam pumps, with a combined capacity of 550 gallons per minute, into a large standpipe on an adjacent hill. There are three miles of 4-inch, 6-inch and 8-inch cast-iron pipe in the distribution system, with 25 fire hydrants. There are 90 consumers.

WATER ANALYSIS.

Laboratory No. 5402. Collected by Waterman; analysis completed December 6, 1912.

Laboratory No. 5882. Collected by J. C. Riggs; analysis completed August 4, 1913.

Bacterial Examination.	*5402*	*5882*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37°—24 hrs.	600	220
Presumptive tests for *B. coli*	600	220
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	3+	5+
in five .1 cc. tubes	1+ 2—	5+

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	5	1.30
Oxygen consumed	1.2	.004
Nitrogen as free ammonia	.012	.086
Nitrogen as alb. ammonia	.058	.004
Nitrogen as nitrites	.01	.5
Nitrogen as nitrates	1	....
Total solids	958	1,080

Mineral Analysis.

SiO_2	19.6	18.4
$Fe_2O_3+Al_2O_3$	2.8	0
Ca	223	219
Mg	39.7	46.6
Na+K	23	32
Cl	42.6	54
SO_4	323	438.9
HCO_3	454	334.8

Hardness group, 14; total solids group, 17-20.

FOWLER.

Population in 1910, 473. Combined water and light plant built by city in 1912. Source of supply, one well 24 inches in diameter for the first 80 feet, and 10 inches in diameter for 20 feet. Pump is of Layne & Bowler type. Water is pumped to a surface reservoir by a 750 g. p. m. centrifugal pump, submerged, and from there to a standpipe by an American centrifugal 350 g. p. m. pump, against a head of 75 feet, to a 75-foot standpipe. Distribution system consists of 2048 feet of 8-inch, 1470 feet of 6-inch, and 8485 feet of 4-inch cast-iron pipe. There are 23 fire hydrants.

Laboratory No. 6274. Collected by E. Wood; analysis completed December 11, 1913.

Bacterial Examination.	*6274*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	....
Agar, at 37° —24 hrs	1	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	0	....
Nitrogen as free ammonia	.018	....
Nitrogen as alb. ammonia	.022	....
Nitrogen as nitrites	trace	....
Nitrogen as nitrates	.1	....
Total solids	291	....

Mineral Analysis.		
SiO_2	47	....
$Fe_2O_3+Al_2O_3$	.1	....
Ca	35	....
Mg	14.7	....
Na+K	33	....
Cl	6	....
SO_4	40.9	....
HCO_3	207.5	....

Hardness group, 3; total solids group, 4.

FRANKFORT.

Population in 1910, 1426. Plant constructed originally by city. Rebuilt in 1914. Source of supply, three wells 7 inches in diameter, one well 10 inches in diameter, 105 feet deep. Water pumped by two deep-well triplex pumps, 105 and 300 gallons per minute, to standpipe 100 feet high, with a capacity of 70,000 gallons. Pumps driven by a 32 hp. gasoline engine or 25 hp. motor. Distribution system: 8-inch, 351 feet; 6-inch, 6240 feet; 4-inch, 9740 feet; 2½-inch, 13,313 feet; 1½-inch, 1775 feet. Fire hydrants, 35; no rental. Consumers, 200; all metered. Daily consumption, 75,000 gallons. Rate for water, 35 cents per thousand, with sliding scale to 9 cents.

WATER ANALYSIS.

Laboratory No. 6036. Collected by Snodgrass; analysis completed September 13, 1913.

Bacterial Examination.	*6036*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	12	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis. Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	0	....
Nitrogen as free ammonia	.006	....
Nitrogen as alb. ammonia	.002	....
Nitrogen as nitrites	.0005	....
Total solids	364	....

Mineral Analysis.		
SiO_2	24.2	....
$Fe_2O_3+Al_2O_3$	0	....
Ca	77	....
Mg	17.9	....
Na+K	14	....
Cl	14	....
SO_4	9.35	....
HCO_3	334.8	....

Hardness group, 5; total solids group, 5.

FRONTENAC.

Population in 1910, 3396. Plant constructed in 1902 by Cherokee & Pittsburg Coal & Mining Co. Purchased by city in 1913. Source of supply, one 8-inch well 1040 feet deep. Pumped by a Luitwieler deep well, 200 g. p. m. triplex pump, and also Luitwieler triplex 350 g. p. m., both motor driven, to reservoir, 350,000-gallon capacity. Distribution system: 6-inch, 90 feet; 4-inch, 4500 feet; 2½-inch, 16,000 feet; 1½-inch, 32,000 feet. Fire hydrants, 29; no rental. Consumers, 603; 14 per cent metered. Daily consumption, 65,000 gallons. Minimum rate for water, 50 cents.

WATER ANALYSIS.

Laboratory No. 5499. Collected by Wm. Monahan; analysis completed January 6, 1913.

Laboratory No. 5968. Collected by Wm. Monahan; analysis completed August 22, 1913.

Bacterial Examination.	*5499*	*5968*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	70	12
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	hyd. sulph.	H_2S
Turbidity	slight	0
Oxygen consumed	5	.7
Nitrogen as free ammonia	.114	.042
Nitrogen as alb. ammonia	.006	.002
Nitrogen as nitrites	....	.002
Nitrogen as nitrates	....	0
Total solids	440	421
Mineral Analysis.		
SiO_2	8.8	28
$Fe_2O_3+Al_2O_3$	2.6	1.4
Ca	56.5	38
Mg	23.8	23.8
Na+K	74.5	100
Cl	102	108
SO_4	30.4	14.4
HCO_3	268.4	283

Hardness group, 4; total solids group, 6.

GARDEN CITY.

Population in 1910, 3171. Plant built by city in 1887. Combined water and light plant rebuilt in 1913. Source of supply, one dug well, 20 feet in diameter, 20 feet deep, four drilled wells, 12 inches in diameter, 45 feet deep. Water pumped by two Buffalo duplex steam pumps, with a capacity of 230 g. p. m. each, also Advance duplex 1000 g. p. m., capacity, and two motor driven centrifugal pumps, 250 g. p. m., each, capacity, to standpipe 20 x 90 feet, capacity 211,000 gallons. Pumps and

motors are driven by two direct connected compound condensing, high-speed engines and generator, capacity 100 and 167½ hp., respectively. Steam plant. Distribution system: 10-inch, 1550 feet; 8-inch, 5425 feet; 6-inch, 11,325 feet; 4-inch, 14,800 feet; 2-inch, 2300 feet. Fire hydrants, 43; no rental. Consumers, 400; 90 per cent metered. Average daily consumption, 500,000 gallons. Rate, 10 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5615. Collected by W. E. Trull; analysis completed March 7, 1913.

Laboratory No. 6449. Changed supply in 1913; collected by W. E. Trull; analysis completed February 18, 1914.

Bacterial Examination.	*5615*	*6449*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	12,000
Agar, at 37°—24 hrs.	15	4—
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0*	0
Oxygen consumed	3	1.10
Nitrogen as free ammonia	.022	0
Nitrogen as alb. ammonia	.084	.012
Nitrogen as nitrites	.002	.001
Nitrogen as nitrates	4	1
Total solids	1,637	290
Mineral Analysis.		
SiO_2	15.8	....
$Fe_2O_3+Al_2O_3$	1.6	....
Ca	224	....
Mg	59.3	....
Na+K	166	....
Cl	59.2	9
SO_4	797	73.2
HCO_3	303	175.6

Hardness group, 13; total solids group, 32.

GIRARD.

Population in 1910, 2600. Water and light plant built in 1893 by the city. Water supplied from two wells 8 inches in diameter by 1146 feet deep. Casing, 8 inches in diameter 470 feet deep. Water pumped by duplex pump, make not stated, 500 g. p. m. capacity, to elevated tank and reservoir having combined capacity of 526,000 gallons. Elevation of the tank, 190 feet. Tank is covered, reservoir not covered. Distribution system: 8-inch, 3000 feet; 6-inch, 5000 feet; 4-inch, 12,000 feet. Fire hydrants, 59; no rental charged. Consumers, 325; 75 per cent metered. Average daily consumption, 120,000 gallons. Rate, 75 cents for 2000 gallons, which is assumed as a minimum charge.

WATER ANALYSIS.

Laboratory No. 5362. Collected by E. R. Walker; analysis completed November 14, 1912.

Laboratory No. 6316. Collected by E. R. Walker; analysis completed January 8, 1914.

Bacterial Examination.	*5362*	*6316*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	....
Agar, at 37° —24 hrs.	2000	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	3—	....
in five .1 cc. tubes	3—	....

Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	H_2S	....
Turbidity	0	0
Oxygen consumed	.9	....
Nitrogen as free ammonia	.37	.124
Nitrogen as alb. ammonia	.03	.006
Nitrogen as nitrites	.003	0
Nitrogen as nitrates	....	.1
Total solids	1310	1391

Chemical Analysis.		
SiO_2	14.6	....
$Fe_2O_3+Al_2O_3$	1.2	....
Ca	76.2	....
Mg	31.0	....
Na+K	388	....
Cl	510	540
SO_4	176	124
HCO_3	315	298

Hardness group, 6; total solids group, 24.

GLASCO.

Population 1910, 720. Combined water and light plant built by city in 1912. Source of supply, one well 10 feet in diameter, 42 feet deep. Water pumped by motor driven triplex 100 g. p. m. pump, to 50,000-gallon tank on 100-foot tower. Distribution system: 6-inch, 3920 feet; 4-inch, 8180 feet. Fire hydrants, 24; no rental. Consumers, 102; all metered. Daily consumption, 40,000 gallons. Minimum rate, $3.25 per quarter, with sliding scale from 30 cents to 20 cents.

WATER ANALYSIS.

Laboratory No. 6081. Collected by E. C. Lemon; analysis completed September 30, 1913.

Bacterial Examination.	*6081*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	3	....
Presumptive tests for *B. coli*	+	....
Number of positive fermentations:		
in one 10 cc. tube	+	....
in five 1 cc. tubes	1+ 4—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.
Results in parts per million.

Oxygen consumed	1	....
Nitrogen as free ammonia	.008	....
Nitrogen as alb. ammonia	.024	....
Nitrogen as nitrites	.003	....
Nitrogen as nitrates	.1	....
Total solids	466	....
Mineral Analysis.		
SiO_2	37	....
$Fe_2O_3+Al_2O_3$	1.6	....
Ca	73	....
Mg	12.2	....
Na+K	79	....
Cl	44	....
SO_4	34.13	....
HCO_3	381	....

Hardness group, 4; total solids group, 7.

GLEN ELDER.

Population in 1910, 565. Waterworks plant built by the city in 1913. Source of supply, one well 12 feet in diameter, 40 feet in depth. Water will be pumped by one deep-well triplex pump, with a capacity of 200 g. p. m., discharging to a 50,000-gallon tank on a 100-foot tower.

WATER ANALYSIS.

Laboratory No. 5018.

Chemical Analysis. Results in parts per million.	*5018*	
Color	none	....
Odor	none	....
Turbidity	clear	....
Oxygen consumed	.29	....
Nitrogen as free ammonia	.006	....
Nitrogen as alb. ammonia	.038	....
Nitrogen as nitrites	.004	....
Nitrogen as nitrates	none	....
Total solids	571	....
Mineral Analysis.		
$Fe_2O_3+Al_2O_3$	.3	....
Cl	59.6	....
SO_4	19.8	....
HCO_3	421	....

GOODLAND.

Population in 1910, 1993. Plant was constructed in 1905 by the city. Source of supply, four 6-inch wells, 165 feet in depth, cased with galvanized iron, into from 12 to 20 feet of coarse gravel. Water is pumped by four 78 g. p. m. deep-well pumps, discharging to a 216,000-gallon standpipe, covered, 90 feet in height. Two of the deep-well pumps are operated by a 15 hp. Wagner electric motor, one by a separate 15 hp. Wagner electric motor, and the fourth by steam at the electric light plant. In addition, a 400 g. p. m. centrifugal pump is held in reserve for fire protection. Distribution system consists of 3532 feet of 10-inch, 11,544 feet of 6-inch,

22,932 feet of 4-inch cast-iron pipe, with 8000 feet of 2-inch wrought-iron pipe. Fire hydrants, 41; no rental. Consumers, 503; all metered. The average daily consumption is 75,000 gallons. Minimum rate, 75 cents per month, and 30 cents for all water used in excess of a certain amount.

WATER ANALYSIS.

Laboratory No. 5282. Collected by C. A. Haskins; analysis completed October 12, 1912.

Laboratory No. 6056. Analysis completed September 16, 1913.

Bacterial Examination.	*5282*	*6056*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	....
Agar, at 37° —24 hrs	5	3,000
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Oxygen consumed	....	.25
Nitrogen as free ammonia	....	.024
Nitrogen as alb. ammonia	....	.110
Nitrogen as nitrites	.004	....
Nitrogen as nitrates	3	3.5
Total solids	264	286
Mineral Analysis.		
SiO_2	40.8	56
$Fe_2O_3+Al_2O_3$	3.4	trace
Ca	33.7	36.40
Mg	11.5	12
Na+K	33	26
Cl	8.0	8
SO_4	24.7	23.8
HCO_3	202	195

Hardness group, 2; total solids group, 4.

GREAT BEND.

Population in 1910, 5500. Combined water and light plant, constructed by Western Water, Light and Traction Company in 1886-'87. At present owned by Great Bend Water and Light Company. Source of supply, four 6-inch and eighteen 5-inch wells, drilled to depth of 70 to 80 feet. Water pumped by Deane compound duplex condensing steam 700 g. p. m. pump, Buffalo compound duplex condensing steam 700 g. p. m. pump, and three 100 hp. motor-driven direct-connected triplex Deane pumps, capacity —. Water pumped to standpipe 12 feet in diameter, 150 feet high, 1,000,000 gallons capacity. Distribution system: 10-inch, 2820 feet; 8-inch, 6080 feet; 6-inch, 19,340 feet; 4-inch, 10,592 feet. Fire hydrants, 75; rental, $45 per year. Daily consumption, 250,000 gallons. Minimum rate, $1.25 per month, with sliding scale. Consumers, 420; 99 per cent metered. The city and all public buildings are supplied free, estimated to equal 66 per cent of the water pumped.

WATER ANALYSIS.

Laboratory No. 4930. Collected by F. A. Moses; analysis completed May 1, 1912.

Laboratory No. 5849. Collected by F. A. Moses; analysis completed July 25, 1913.

Bacterial Examination.	*4930*	*5849*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	31,000	....
Agar, at 37° —24 hrs.	3,900	4
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis.		
Results in parts per million.		
Color	c	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	0	.19
Nitrogen as free ammonia	.002	.010
Nitrogen as alb. ammonia	.039	.178
Nitrogen as nitrites	0	.001
Nitrogen as nitrates	.6	.5
Total solids	542	615
Mineral Analysis.		
SiO_2	13.6	....
Ca	102.3	....
Mg	18.75	....
Na+K	79	....
Cl	66	63.6
SO_4	231	245.2
HCO_3	206.5	178.1

Hardness group, 6; total solids group, 9.

GREEN.

Population in 1910, 289. Plant built by city in 1911. Plant used for fire protection only. Source of supply, well 862 feet deep. Two pumps driven by gasoline engine, discharge to 700,000-gallon tank, 40 feet high.

WATER ANALYSIS.

Laboratory No. 5978. Collected by G. H. Young; analysis completed August 29, 1913.

Bacterial Examination.	*5978*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	60	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis. Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	.45	....
Nitrogen as free ammonia	.006	....
Nitrogen as alb. ammonia	.002	....
Nitrogen as nitrites	.004	....
Nitrogen as nitrates	1	....
Total solids	459	....

Mineral Analysis.		
SiO_2	19.8	....
$Fe_2O_3+Al_2O_3$	1	....
Ca	50	....
Mg	43	....
Na+K	50	....
Cl	41	....
SO_4	30.1	....
HCO_3	390.5	....

Hardness group, 6; total solids group, 7.

GREENLEAF.

Population in 1910, 781. Plant built by city in 1887; rebuilt, 1907. Source of supply, three 10-inch wells 100 feet deep. Water pumped by American Well Works pump, 125 g. p. m. capacity, and American Well Works 75 g. p. m. deep-well pump, to a 250,000-gallon standpipe 12 x 100 feet. Pumps driven by one 12 and one 15 hp. Fairbanks-Morse oil engine. Distribution system: 8-inch, 1500 feet; 6-inch, 8500 feet; 3-inch, 4100 feet. Fire hydrants, 28. Consumers, 245; 15 per cent metered. Daily consumption, 80,000 gallons. Minimum rate, $2 per quarter, with sliding scale from 15 cents to 10 cents per thousand.

WATER ANALYSIS.

Laboratory No. *5355*. Collected by Z. Snyder; analysis completed November 12, 1912.

Laboratory No. 6096. Collected by J. A. Ayres; analysis completed October 5, 1913.

Bacterial Examination.	*5355*	*6096*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	200	20
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	.6
Nitrogen as free ammonia	.018	.002
Nitrogen as alb. ammonia	.062	.01
Nitrogen as nitrites	.004	.004
Nitrogen as nitrates	2.5	1.0
Total solids	815	855

Mineral Analysis.		
SiO_2	20.6	....
$Fe_2O_3+Al_2O_3$	2.2	....
Ca	183.2	....
Mg.	31.2	....
Na+K	22	....
Cl	20	25
SO_4	309	110.3
HCO_3	357	356.5

Hardness group, 11; total solids group, 14.

HALSTEAD.

Population in 1910, 1004. Plant built in 1909 by city. Source of supply, four wells, 8 inches in diameter, 100 feet deep. Water pumped by two 300 g. p. m. triplex power pumps, discharging to 50,000-gallon tank on 100-foot tower. Pumps driven by two 35 hp. gasline engines. Distribution system: 8-inch, 4725 feet; 6-inch, 4200 feet; 4-inch, 26,285 feet. Fire hydrants, 40; no rental. Consumers, 217. Daily consumption, 40,000 gallons. Minimum rate, 50 cents per quarter.

WATER ANALYSIS.

Laboratory No. 5381. Collected by E. Walbert; analysis completed, November 22, 1912.

Laboratory No. 6107. Collected by J. D. Lange; analysis completed October 14, 1913.

Bacterial Examination.	*5381*	*6107*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	50	25
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	3
Nitrogen as free ammonia	.146	.128
Nitrogen as alb. ammonia	.042	.036
Nitrogen as nitrites	0	.001
Nitrogen as nitrates	0	....
Total solids	274	271
Mineral Analysis.		
SiO_2	18.4	39.8
$Fe_2O_3+Al_2O_3$	3.2	2.4
Ca	38.3	45.6
Mg	5.3	8.5
Na+K	69	41
Cl	12.4	11
SO_4	27.9	23.87
HCO_3	249	239

Hardness group, 2; total solids group, 5.

HANOVER.

Population in 1910, 1039. Plant built by city in 1895. Source of supply, one well 12 feet in diameter, 46 feet deep. Water pumped by Gould 180 g. p. m. triplex pump and Gould 155 g. p. m. triplex pump to standpipe 100 feet high, capacity 55,500 gallons. Pumps driven by Olds 35 hp. and Fairbanks-Morse 22 hp. gasoline engines. Distribution system: 8-inch, 4500 feet; 6-inch, 5400 feet; 4-inch, 7200 feet; 2-inch, 1350 feet. Fire hydrants, 31; no rental. Consumers, 140; 30 per cent metered. Daily consumption, 10,000 gallons. Minimum charge, $4 per year.

WATER ANALYSIS.

Laboratory No. 4924. Collected by D. Spence; analysis completed April 30, 1912.

Laboratory No. 6344. Collected by B. H. Dicker; analysis completed January 19, 1914.

Bacterial Examination.	*4924*	*6344*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	26,000	....
Agar, at 37°—24 hrs	3,000	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	3—	....
in five .1 cc. tubes	3—	....
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	0	c
Odor	0	0
Turbidity	c	0
Oxygen consumed	.52	.2
Nitrogen as free ammonia	.002	.006
Nitrogen as alb. ammonia	.036	.048
Nitrogen as nitrites	.002	.004
Nitrogen as nitrates	1.5	1
Total solids	1,141	1,100
Mineral Analysis.		
SiO_2	24.6	....
$Fe_2O_3+Al_2O_3$	2.2	....
Ca	197.5	....
Mg	105	....
Na+K	27	....
Cl	28.4	18
SO_4	584	464.88
HCO_3	405.7	388

Hardness group, 18; total solids group, 21.

HARPER.

Population in 1910, 1638. Combined water and light plant built by city in 1887. Rebuilt in 1907. Well deepened in 1913. Source of supply, one well 20 feet in diameter, 40 feet deep. Water pumped by Smith-Vaile simple 500 g. p. m. and Smith-Vaile 350 g. p. m. pumps to standpipe 120 feet high, capacity 150,000 gallons. Distribution system, 5 miles of 10-inch and smaller. Fire hydrants, 65; no rental. Consumers, 250; all metered. Daily consumption, 200,000 gallons. Minimum rate, 75 cents per month and 15 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5493. Collected by Crocker; analysis completed January 10, 1913.

Laboratory No. 6363. Collected by Crocker; analysis completed January 21, 1914.

Bacterial Examination.	*5493*	*6363*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	4,000
Agar, at 37° —24 hrs.	75	100
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.5	1.6
Nitrogen as free ammonia	.002	.094
Nitrogen as alb. ammonia	.012	.024
Nitrogen as nitrites	0	0
Nitrogen as nitrates	.3	0.7
Total solids	283	286
Mineral Analysis.		
SiO_2	22.6	....
$Fe_2O_3+Al_2O_3$	1	....
Ca	53.5	....
Mg	10.2	....
Na+K	36.8	....
Cl	20	20
SO_4	17.6	18.5
HCO_3	256	256

Hardness group, 3; total solids group, 4.

HAVENSVILLE.

Population in 1910, 412. Plant built by city in 1908. Source of supply, one well 12 feet in diameter, 25 feet deep. Water pumped by Myers Bulldozer 24 g. p. m. pump, driven by 4 hp. gasoline engine, to wooden tank on stone tower, with a capacity of 33,000 gallons. Distribution system: 6-inch, 2200 feet; 4-inch, 2550 feet; 2-inch, 1050 feet. Fire hydrants, 13; no rental. Consumers, 58; 98 per cent metered. Daily consumption, 10,000 gallons. Minimum rate 50 cents per month, with a sliding scale from 30 cents to 20 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5407. Collected by T. McKee; analysis completed November 22, 1912.

Laboratory No. 5975. Collected by Bigelow; analysis completed August 1, 1913.

Bacterial Examination.	*5407*	*5875*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	250	....
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	3—	1+ 4—
in five .1 cc. tubes	3—	....

Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1	1.8
Nitrogen as free ammonia	.084	.008
Nitrogen as alb. ammonia	.036	.004
Nitrogen as nitrites	.03	.005
Nitrogen as nitrates	4	1
Total solids	909	940

Mineral Analysis		
SiO_2	10.4	23
$Fe_2O_3+Al_2O_3$	1	0
Ca	205	204
Mg	32.2	35
Na+K	41.4	22
Cl	126	135
SO_4	247.5	227.8
HCO_3	364	332.4

Hardness group, 12; total solids group, 16.

HAYS CITY.

Population in 1910, 1961. Water is secured from three brick-cased dug wells from 45 to 65 feet deep, and is pumped by two Smith-Vaile triplex and two deep-well pumps to two tanks, having a capacity of 50,000 gallons and 100,000 gallons respectively. Distribution system: 8-inch, 3250 feet; 6-inch, 5375 feet; 4-inch, 25,500 feet. Fire hydrants, 66; no rental. Consumers, 260; 100 per cent metered. Minimum rate 50 cents per month, with rate of 15 cents per thousand gallons water.

NOTE.—Includes pipe laid in 1915.

WATER ANALYSIS.

Laboratory No. 5540. Collected by G. Phillips; analysis completed January 25, 1913.

Laboratory No. 5981. Collected by K. C. Haas; analysis completed August 28, 1913.

Bacterial Examination.	*5540*	*5981*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	20	130
Presumptive tests for B. *coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	oily
Turbidity	0	0
Oxygen consumed	.6	1.9
Nitrogen as free ammonia	.012	.008
Nitrogen as alb. ammonia	.034	.028
Nitrogen as nitrites	.003	.3
Nitrogen as nitrates	8	4.5
Total solids	474	491

Mineral Analysis.

SiO_2	50.4	....
$Fe_2O_3+Al_2O_3$	3	....
Ca	106.5	....
Mg	11.4	....
Na+K	17	....
Cl	30	42
SO_4	32.6	....
HCO_3	332.4	312.5

Hardness group, 6; total solids group, 7.

HERINGTON.

Population in 1910, 3273. Water and light plant built in 1908 by the city. Additional water supply secured in 1914. Water supplied from three wells 8 inches in diameter by 100 feet deep and two springs. Prime movers, 2 Erie City direct connected 225 hp. engines and one Skinner direct connected 135 hp. engine. Water pumped by one Deane compound duplex 450 g. p. m. pump, one Deane duplex 750 g. p. m. pump, against 174-foot head; one triplex 150 g. p. m. capacity and one triplex 250 g. p. m. capacity. Standpipe, 127 feet high, 70,000-gallon capacity, covered. Distribution system not specified. Fire hydrants, 59; no rental. Consumers, 320; all metered. Minimum rate, 50 cents per month. First 5000 gallons, 20 cents per thousand; next 10,000 gallons, 15 cents per thousand; over 15,000 gallons, 10 cents per thousand.

WATER ANALYSIS.

Laboratory No. 4411. Source, artesian well; collected by E. W. Jones; analysis completed June 22, 1911.

Laboratory No. 6105. Source, tap; analysis completed October 14, 1913.

Bacterial Examination.	*4411*	*6105*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	....	100
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—

Chemical Analysis.

Results in parts per million.

Nitrogen as nitrates	0	....
Total solids	2,694	....

Mineral Analysis.		
SiO_2	15.8	....
$Fe_2O_3+Al_2O_3$	10	....
Ca	517.164	....
Mg	142.56	....
Na+K	41	....
Cl	64	....
SO_4	1,493.8	....
HCO_3	337.77	....

HIAWATHA.

Population in 1910, 2974. Combined water and light plant built in 1887 by the city. Rebuilt in 1907-'08. Spring supply added in 1911. Source of supply, three wells, 6-10-12 feet in diameter, 25-30-35 feet deep. Also springs collected in reservoir with a capacity of 450,000 gallons. Water pumped from wells by two Deane compound duplex 400 g. p. m. each, steam pumps, driven by a Murray-Corliss 100 hp. engine. Water pumped from springs by two American centrifugal motor-driven 400 g. p. m. each, to standpipe 133 feet high, with a capacity of 112,000 gallons. Distribution system: 10-inch, 1320 feet; 8-inch, 15,300 feet; 6-inch, 8400 feet; 4-inch, 28,300 feet. Fire hydrants, 57; no rental. Consumers, 565; 95 per cent metered. Daily consumption, 190,000 gallons. Minimum rate charged for water, 25 cents per month. Rate for one thousand gallons, 30 cents.

WATER ANALYSIS.

Laboratory No. 5263. Collected by Liebengood; analysis completed October 7, 1912.

Laboratory No. 5264. Collected by Liebengood; analysis completed October 7, 1912.

Bacterial Examination.	*5263*	*5264*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	520	1,700
Presumptive tests for *B. coli*	+	+
Number of postive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	3+	3+
in five .1 cc. tubes	2—	2—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.7	.7
Nitrogen as free ammonia	.014	.01
Nitrogen as alb. ammonia	.014	.006
Nitrogen as nitrites	.004	.004
Nitrogen as nitrates	2.5	1.2
Total solids	334	338

Mineral Analysis.		
SiO_2	22.6	24.6
$Fe_2O_3+Al_2O_3$	7.6	9.8
Ca	74.9	85
Mg	21.83	23.7
Na+K	2	0
Cl	5.2	5.8
SO_4	1.48	19.2
HCO_3	330	337.5

Hardness group, 6; total solids group, 5.

HIGHLAND.

Population in 1910, 730. Water plant built in 1914 by the city. Water taken from one well 12 feet in diameter by 52 feet deep, cased in concrete. Water found in 6-foot layer of sand and gravel. Water pumped by two electrically-driven triplex pumps having a capacity of 135 gallons per minute. Standpipe 120 feet high, 50,000 gallons capacity, covered. Consumers, 40; all metered. Minimum rate, 50 cents per month. Rate per 1000 gallons, 30 cents.

WATER ANALYSIS.

Laboratory No. 7038. Collected by W. M. Boone; analysis completed October 3, 1914.

Bacterial Examination.	*7038*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	60	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	.9	....
Nitrogen as free ammonia	.022	....
Nitrogen as alb. ammonia	.04	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	0	....
Total solids	140	....
Mineral Analysis.		
Cl	12	....
SO_4	trace	....
HCO_3	86.5	....

Hardness group, 1; total solids group, 1.

HILL CITY.

Population in 1910, 983. Plant built by city in 1911. Source of supply, one well 20 feet in diameter, 28 feet deep, with cement casing. Water pumped by triplex pump, capacity of 1000 g. p. m., driven by two St. Marys oil engines, 30 and 40 hp. each. Discharge to standpipe

75,000-gallon capacity, 120 feet high. Fire hydrants, 50; no rental. Consumers, 89. Daily consumption, 60,000 gallons. Rate 50 cents per month and 10 cents per thousand.

WATER ANALYSIS.

Laboratory No. 6200. Collected by A. J. Wilson; analysis completed November 1, 1913.

Bacterial Examination.	*6200*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	2	....
Presumptive tests for *B. coli*	—	....
Number of postive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	6.7	....
Nitrogen as free ammonia	.026	....
Nitrogen as álb. ammonia	.094	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	.7	....
Total solids	549	....
Mineral Analysis.		
SiO_2	33.6	....
$Fe_2O_3+Al_2O_3$	2	....
Ca	118.7	....
Mg	19.3	....
Na+K	28	....
Cl	16	....
SO_4	133.7	....
HCO_3	325	....

Hardness group, 5; total solids group, 9.

HOISINGTON.

Population in 1910, 1975. Combined water and light plant built by city in 1906. Source of supply, one well 13 feet in diameter, 55 feet deep. Water pumped by two Smith-Vaile duplex steam pumps, 500 g. p. m. capacity, or a Lutweiler deep-well pump, 90 g. p. m., and American deep-well 185 g. p. m. motor-driven pump. Discharge to 16 x 100-foot, 160,000-gallon capacity standpipe. Distribution system: 6-inch, 1650 feet; 4-inch, 4800 feet; 2-inch, 24,600 feet. Fire hydrants, 53; rental $35 per year each. Consumers, 390; all metered. Consumption, 110,000 gallons daily. Rate charged, 20 cents per thousand.

WATER ANALYSIS.

Laboratory No. 4944. Collected by Williams; analysis completed May 8, 1912.

Laboratory No. 6224. Collected by O. Bulter; analysis completed November 13, 1913.

Bacterial Examination.	*4944*	*6224*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	200,000	....
Agar, at 37° —24 hrs.	60,000	450
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	+
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	0	1.5
Nitrogen as free ammonia	.03	.016
Nitrogen as alb. ammonia	.058	.044
Nitrogen as nitrites	0	0
Nitrogen as nitrates	.125	.5
Total solids	284	332
Mineral Analysis.		
SiO_2	23	27
$Fe_2O_3+Al_2O_3$	1	1.7
Ca	106.5	68
Mg	11.26	10.7
Na+K	29.2	39
Cl	42	12
SO_4	25.6	12.8
HCO_3	353	334.8

Hardness group, 6; total solids group, 5.

HOLTON.

Population in 1910, 2842. Combined water and light plant built by the city in 1907. The present supply is secured from five wells, 6 inches to 8 feet in diameter, from 62 feet to 97 feet in depth, into about 6 feet of sand and gravel. The water is pumped by two electric plunger pumps, with a capacity of 120 g. p. m. each, and one electric plunger pump, with a capacity of 60 g. p. m., into a large surface reservoir with a capacity of 225,000 gallons. From here it is pumped by a Worthington turbine 400 g. p. m. and a Worthington piston pump against a head of 160 feet into the distribution system. Distribution system: 8-inch, 1500 feet; 6-inch, 11,320 feet; 4-inch, 26,635 feet; 2-inch, 4000 feet. There are 42 fire hydrants for which a rental of $2000 a year is paid. There are 237 domestic and 86 business consumers, all metered. The daily consumption will average 150,000 gallons. A minimum rate of 60 cents per month is charged, with a graduated scale from 30 cents to 25 cents for large quantities.

WATER ANALYSIS.

Laboratory No. 5007. Source, tap; analysis completed June 8, 1912.

Bacterial Examination.	*5007*	
Presumptive tests for *B. coli*	neg.	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....
in five .01 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Turbidity	c	....
Oxygen consumed	.5	....
Nitrogen as free ammonia	.052	....
Nitrogen as alb. ammonia	.058	....
Nitrogen as nitrites	.004	....
Nitrogen as nitrates	.15	....
Total solids	514	....

Mineral Analysis.

SiO_2	13.6	....
$Fe_2O_3+Al_2O_3$	1.8	....
Ca	82.3	....
Mg	11.24	....
Cl	158.4	....
SO_4	38.2	....
HCO_3	214.5	....

HOLYROOD.

Population in 1910, 361. Plant built in 1908 by city. Source of supply, two wells 120 feet deep. Water pumped by two 88 g. p. m. pumps, belt connected to 10 hp. Fairbanks-Morse gasoline engine. Discharge into 40,000-gallon tank on 120-foot tower. Distribution system: 8-inch, 1020 feet; 6-inch, 2508 feet; 4-inch, 4452 feet. Fire hydrants, 24; no rental. Consumers, 55; 95 per cent metered. Minimum rate of $1 per month, 15 cents per one hundred cubic feet.

WATER ANALYSIS.

Laboratory No. 4910. Collected by Haska; analysis completed April 22, 1912.

Laboratory No. 5945. Collected by S. Andrea; analysis completed August 16, 1913.

Bacterial Examination.	*4910*	*5945*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	915	....
Agar, at 37° —24 hrs.	2,150	100
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	0	brown
Odor	0	0
Turbidity	10	30
Oxygen consumed	.23	.3
Nitrogen as free ammonia	.014	.004
Nitrogen as alb. ammonia	.056	.006
Nitrogen as nitrites	0	.002
Nitrogen as nitrates	.15	0
Total solids	380	458

Mineral Analysis.

SiO_2	60.6	67.6
$Fe_2O_3+Al_2O_3$	5.4	8
Ca	94.6	29
Mg	8.39	9
Na+K	36.2	81
Cl	36.6	24
SO_4	20.25	18.3
HCO_3	337.5	344.4

Hardness group, 5; total solids group, 7.

HUMBOLDT.

Population in 1910, 2548. Plant built by city in 1913. Source of supply, one well 20 feet in diameter, 30 feet deep. Two Snow duplex pumps, 600 g. p. m. capacity each, driven by a Deane 80 hp. gasoline engine, discharge to an elevated tank, capacity of 70,000 gallons, on a 100-foot tower. Distribution system: 10-inch, 3900 feet; 8-inch, 3200 feet; 6-inch, 16,400 feet; 4-inch, 12,000 feet. Fire hydrants, 54; no rental. Consumers, 250; all metered. Daily consumption, 100,000 gallons. Rate, 25 cents per thousand, graduated down to 8 cents.

NOTE.—Plans have been prepared for a modern filtration plant, having a capacity of approximately 300,000 gallons per day.

WATER ANALYSIS.

Laboratory No. 6043. Collected by Schoffner; analysis completed September 15, 1913.

Laboratory No. 6291. Collected by city; analysis completed December 20, 1913.

Bacterial Examination.	*6043*	*6291*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	500	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	+	....
in five 1 cc. tubes	2+ 3—	....
in five .1 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	gas
Turbidity	10	0
Oxygen consumed	3.8	2.4
Nitrogen as free ammonia	.006	.016
Nitrogen as alb. ammonia	.008	.014
Nitrogen as nitrites	.002	.002
Nitrogen as nitrates	0	.4
Total solids	352	349

Mineral Analysis.

SiO_2	....	18.2
$Fe_2O_3+Al_2O_3$	....	.6
Ca	....	88
Mg	....	13
Na+K	....	10
Cl	22	13
SO_4	trace	52.7
HCO_3	317.5	266

Hardness group, 5; total solids group, 5.

HUTCHINSON.

Population in 1910, 16,364. Plant built in 1886, by Hutchinson Water, Light & Power Co. Owned at present by the United Water, Gas & Electric Co. Source of supply, 40 wells, 6 and 8 inches in diameter, 60 and 85 feet in depth. Water pumped by two 2-stage DeLaval centrifugal pumps, capacity, 4,500,000 gallons daily; one Holly Gaskill, capacity 2,500,000 gallons daily, and four Worthington motor-driven centrifugal, capacity 2,100,000 gallons daily. Prime mover, two 110 hp. DeLaval steam turbines, one 100 hp. compound condensing Gaskill engines. Direct pressure is maintained. Distribution system: 12-inch, 2000 feet; 10-inch, 4000 feet; 8-inch, 1400 feet; 6-inch, 148,600 feet; 4-inch, 15,200 feet; 2-inch, 2000 feet. Fire hydrants, 363; rental, $34.40 per year each. Consumers, 2898; all metered. Minimum rate, 50 cents per month, with special rates for various users.

WATER ANALYSIS.

Laboratory No. 5480. Collected by Lebon; analysis completed January 7, 1913.

Laboratory No. 6119. Collected by Dr. Shoore; analysis completed October 15, 1913.

Bacterial Examination.	*5480*	*6119*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	20	9
Presumptive tests for B. *coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	oily	0
Turbidity	0	0
Oxygen consumed	1.5	1.8
Nitrogen as free ammonia	.052	0
Nitrogen as alb. ammonia	.056	.06
Nitrogen as nitrites	.004	.001
Nitrogen as nitrates	.7	.5
Total solids	966	915
Mineral Analysis.		
SiO_2	13.2	18
$Fe_2O_3+Al_2O_3$	1.8	9.5
Ca	125.5	107
Mg	20.25	31.7
Na+K	171	243
Cl	298	406
SO_4	141.6	129.2
HCO_3	241	264

Hardness group, 7; total solids group, 16.

JAMESTOWN.

Population in 1910, 462. Combined water and light plant, built by the city in 1910. The source of supply is two wells 10 inches in diameter and 160 feet deep, cased with steel into 30 feet of fine sand. Water is pumped by two 65 and 35 g. p. m. deep-well pumps, driven by a 15 and 7½ hp. motor into a 36,000-gallon covered tank on a 100-foot tower. Distribution system: 6-inch, 4400 feet; 4-inch, 4920 feet of cast-iron pipe; 2-inch, 1100 feet. Fire hydrants, 8. Consumers, 112; 75 per cent metered. Daily consumption, 18,000 gallons. A minimum rate of 75 cents per month is charged for water, with a rate of 30 cents per thousand for large amounts.

WATER ANALYSIS.

Laboratory No. 5547. Collected by Vanderbark; analysis completed January 24, 1913.

Laboratory No. 6180. Collected by W. R. Barton; analysis completed October 25, 1913.

Bacterial Examination.	*5547*	*6180*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	5	6
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	1.4
Nitrogen as free ammonia	.082	.086
Nitrogen as alb. ammonia	.006	.06
Nitrogen as nitrites	.001	trace
Nitrogen as nitrates	0	0
Total solids	464	461
Mineral Analysis.		
SiO_2	17.8	....
$Fe_2O_3+Al_2O_3$	2	....
Ca	101	....
Mg	12.06	....
Na+K	51.6	....
Cl	26	29
SO_4	87.5	74.8
HCO_3	349	352

Hardness group, 6; total solids group, 7.

JETMORE.

Population in 1910, 317. Plant built in 1915. Water is pumped from one well 8 feet 8 inches in diameter by 35 feet deep, to a 50,000-gallon tank on a 100-foot tower, by a two-stage centrifugal pump. Distribution system: 6-inch, 5000 feet; 4-inch, 5000 feet. Fire hydrants, 20. New supply 1915.

JUNCTION CITY.

Population in 1910, 5598. Plant built by city in 1887. Source of supply, 13 wells 6, 7 and 8 inches in diameter, two wells 24 inches in diameter. Water pumped by one Laidlaw, Dunn, Gordon, 1,500,000 gallons daily, and one Gear 2,000,000 gallons daily cross-compound condensing pumps, into 500,000-gallon reservoir 85 feet in diameter, 16 feet deep, 200 feet above the city, on a hill. A dry vacuum pump operates on the pump suction. Distribution system: 12-inch, 200 feet; 10-inch, 17,820 feet; 6-inch, 8840 feet; 4-inch, 9913 feet; 2-inch, 15,468 feet. Fire hydrants, 100; rental, $35 yearly. Consumers, 1332; 99 per cent metered. Daily consumption, 621,000 gallons. Minimum rate charged for use, 15 cents.

WATER ANALYSIS.

Laboratory No. 5582. Collected by F. R. Conlan; analysis completed February 14, 1913.

Laboratory No. 5990. Collected by F. R. Conlan; analysis completed August 2, 1913.

Bacterial examination	*5582*	*5990*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	30	16
Presumptive tests for *B. coli*.	—	—
No. of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.2	0
Nitrogen as free ammonia	.006	.01
Nitrogen as alb. ammonia	.026	.014
Nitrogen as nitrites	.001	.0005
Nitrogen as nitrates	.7	.5
Total solids	352	398
Mineral Analysis.		
SiO_2	17.2	32
$Fe_2O_3+Al_2O_3$	2.8	1.2
Ca	80	52
Mg	16.6	19.8
Na+K	24	55
Cl	20	34
SO_4	36.2	44.4
HCO_3	310	295.5

Hardness group, 5; total solids group, 6.

KANOPOLIS.

Population in 1910, 577. Combined water and light plant built in 1913 by the city. Source of supply, one 15-inch well, 40 feet deep. Compound duplex steam pump, with a capacity of 326 g. p. m. discharges to 60,000-gallon tank on a 100-foot tower. Pump is driven by 50 hp. horizontal Skinner steam engine. Distribution system: 8-inch, 1470 feet; 6-inch, 4370 feet; 4-inch, 10,000 feet. Fire hydrants, 33; no rental. Consumers, 20; all metered. Daily consumption, 1000 gallons.

NOTE.—This is a new plant, just built.

KENSINGTON.

Population in 1910, 497. Combined water and light plant built by the city in 1910. Supply is secured from two wells 20 and 10 feet in diameter, 48 feet and 62 feet in depth, cased with brick. Water is pumped by two Luitwieler pumps 200 and 60 g. p. m., respectively. There is an International 50 hp. coal oil engine and a Fairbanks-Morse 20 hp. coal oil engine. Water is pumped to a 75,000-gallon covered tank on a 100-foot tower. Distribution system: 6-inch, 3729 feet; 4-inch, 9713 feet cast-iron pipe, and 2-inch, 7900 feet. There are 26 fire hydrants for which no rental is charged. There are 141 consumers, all metered. Daily consumption is 40,000 gallons. Minimum rate of $6 per year is charged, with a rate of 15 cents per thousand for large amounts.

WATER ANALYSIS.

Laboratory No. 4981. Collected by O. H. Hinman; analysis completed May 16, 1912.

Laboratory No. 6545. Collected by Peter Pyle; analysis completed April 17, 1914.

Bacterial Examination.	*4981*	*6545*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	10,500	1,800
Agar, at 37°—24 hrs.	350	2,500
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	1+ 4—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	.54	1.08
Nitrogen as free ammonia	.006	.028
Nitrogen as alb. ammonia	.08	.044
Nitrogen as nitrites	0	trace
Nitrogen as nitrates	.6	0
Total solids	462	570
Mineral Analysis.		
SiO_2	32.8	....
$Fe_2O_3+Al_2O_3$	8.2	....
Ca	128	....
Mg	14.65	....
Na+K	47	....
Cl	41.2	21.2
SO_4	90.4	86.39
HCO_3	405	395.5

Hardness group, 7; total solids group, 9.

KINGMAN.

Population in 1910, 2570. Plant built in 1905 by the city. Combined water and light plant. Source of supply springs 3½ miles west of city. Flows by gravity through wood pipe to reservoir at pumping station. Also six 4-inch wells, 50 feet in depth, at plant for emergency supply. Water pumped by two 300 g. p. m. triplex pumps to elevated tank

70,000-gallon capacity, on 100-foot tower. Pumps driven by motor with two Olds horizontal gas engines, 25 hp. each. Distribution system: 8-inch, 5800 feet; 6-inch, 12,200 feet; 4-inch, 9000 feet; 3-inch, 4800 feet; 2-inch, 7000 feet; 1¼-inch, 8800 feet. Fire hydrants, 52; no rental. Consumers, 535; 95 per cent metered. Average daily consumption, 230,000 gallons. Minimum rate 50 cents per month.

WATER ANALYSIS.

Laboratory No. 4973. Collected by A. B. Fell; analysis completed May 15, 1912.

Laboratory No. 6055. Analysis Completed September 19, 1913.

Bacterial Examination.	*4973*	*6055*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	Liq.	....
Agar, at 37° —24 hrs.	2,640	30
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	....	+
in five 1 cc. tubes	1+ 2—	3+ 2—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.24	0
Nitrogen as free ammonia	.01	.001
Nitrogen as alb. ammonia	.058	.048
Nitrogen as nitrites	0	.004
Nitrogen as nitrates	1.2	2.5
Total solids	132	193
Mineral Analysis.		
SiO_2	27.6	2
$Fe_2O_3+Al_2O_3$	4.4	.5
Ca	40.8	40
Mg	4.95	6.5
Na+K	11.4	0
Cl	12.4	14
SO_4	9.55	....
HCO_3	144.5	129.3

Hardness group, 2; total solids group, 2.

KINSLEY.

Population in 1910, 1547. Plant built in 1906 by the city. The source of supply is one well 12 feet in diameter and 38 feet deep, cased with corrugated galvanized iron to the third underflow of the Arkansas river. The water is pumped by a 350 g. p. m. centrifugal pump, driven by a Fairbanks-Morse Solar oil engine. Standpipe is 16½ feet in diameter and 120 feet in height. There are 39 fire hydrants; 125 consumers, with 90 per cent metered. Average daily consumption is 90,000 gallons. A rate of $1 per month is charged for water and 15 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5473. Collected by Wilson; analysis completed December 31, 1912.

Laboratory No. 6004. Collected by M. A. Wilson; analysis completed September 5, 1913.

Bacterial Examination.	*5473*	*6004*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	10	10,000
Presumptive tests for *B. coli*	+	+
No. of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	1+ 2—	5+
in five .1 cc. tubes	3—	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	9	1.1
Nitrogen as free ammonia	.01	.004
Nitrogen as alb. ammonia	.012	.006
Nitrogen as nitrites	0	.003
Nitrogen as nitrates	.5	2.0
Total solids	660	822
Mineral Analysis.		
SiO_2	15.8	25.4
$Fe_2O_3+Al_2O_3$	1.6	1.6
Ca	107	117
Mg	24.7	32
Na+K	62.8	79
Cl	40	46
SO_4	269	320
HCO_3	207	241.5

Hardness group, 7; total solids group, 14.

KIOWA.

Population in 1910, 1520. Combined water and light plant built in 1908 by the city. Water is taken from one well 18 feet in diameter and 20 feet deep, cased with brick, in the valley of the Medicine river. Pumped by two compound duplex steam pumps, 500 g. p. m. capacity or one 200 g. p. m., direct-acting motor-driven triplex pump, into a reservoir through 4000 feet of 6-inch cast-iron pipe. Distribution system: 8-inch, 5122 feet; 6-inch, 2300 feet; 4-inch, 17,232 feet cast-iron pipe, in addition to 4000 feet of 6-inch pipe in the line to the reservoir. There are 31 fire hydrants.

WATER ANALYSIS.

Laboratory No. 5479. Collected by R. Buchanan; analysis completed December 31, 1912.

Laboratory No. 6078. Collected by L. E. Goff; analysis completed October 1, 1913.

Bacterial Examination.	*5479*	*6078*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	30	250
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	5+
in five .1 cc. tubes	3—	3+
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	mouldy	0
Turbidity	0	0
Oxygen consumed	2.5	0
Nitrogen as free ammonia	.042	.002
Nitrogen as alb. ammonia	.092	.13
Nitrogen as nitrites	.025	.08
Nitrogen as nitrates	15	6.5
Total solids	792	457
Mineral Analysis.		
SiO_2	11.2	13.8
$Fe_2O_3 + Al_2O_3$	1.4	1.8
Ca	129.5	102
Mg	52.6	22
Na+K	20	9
Cl	28	40
SO_4	242	85.4
HCO_3	334.4	276

Hardness group, 10; total solids group, 14.

KIRWIN.

Population in 1910, 626. Waterworks plant built by the city in 1911. Source of supply four wells, 12 inches in diameter and 54 feet deep, into 28 feet of sand and gravel. Wells cased with galvanized iron casing. Water is pumped into a 75,000-gallon elevated tank on a 100-foot tower. Distribution system: 6-inch, 4340 feet; 4-inch, 15,000 feet; 2-inch, 12,000 feet. There are 28 fire hydrants.

WATER ANALYSIS.

Laboratory No. 5488. Collected by John Butler; analysis completed January 8, 1913.

Bacterial Examination.	*5488*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	70	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	3—	....
in five .1 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	c	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	7.6	....
Nitrogen as free ammonia	.084	....
Nitrogen as alb. ammonia	.032	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	trace	....
Total solids	477	....

Mineral Analysis.

SiO_2	38.6	....
$Fe_2O_3+Al_2O_3$	3	....
Ca	116	....
Mg	19.9	....
Na+K	17.2	....
Cl	14	....
SO_4	59.4	....
HCO_3	400.5	....

Hardness group, 7; total solids group, 8.

LA CYGNE.

Population in 1910, 1000. Water and light plant built in 1912 by the city. Water supplied from one well 25 feet in diameter by 40 feet deep. Cased with brick. Water found in 6-foot strata of gravel. Prime mover, 40 hp. Erie steam engine. Water pumped by one 500 g. p. m. Canton Hughes compound pump. Distribution system: 8-inch, 3960 feet; 6-inch, 7920 feet; 4-inch, 5300 feet; 2-inch, 1320 feet. Fire hydrants, 23; no rental. Consumers, 100; 33⅓ per cent metered. Average daily consumption, 20,000 gallons. Minimum rate, 50 cents per month. Rate for 1000 gallons, 25 cents.

WATER ANALYSIS.

Laboratory No. 5545. Collected by W. B. Cline; analysis completed January 23, 1913.

Laboratory No. 6151. Collected by W. A. Stolper; analysis completed October 20, 1913.

Bacterial Examination.	*5545*	*6151*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	65	150
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	4+ 1—	5—
in five .1 cc. tubes	....	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.6	.65
Nitrogen as free ammonia	.042	.012
Nitrogen as alb. ammonia	.068	.022
Nitrogen as nitrites	.005	.0005
Nitrogen as nitrates	25	6.0
Total solids	882	829

Mineral Analysis.		
SiO_2	18.6	20.2
$Fe_2O_3+Al_2O_3$	1.2	1.6
Ca	198.5	195
Mg	16.15	20
Na+K	48	35
Cl	54	64
SO_4	209	194.2
HCO_3	405	420

Hardness group, 11; total solids group, 15.

LARNED.

Population in 1910, 2910. Plant built in 1886 by Larned Water Company. Purchased by city in 1906. Source of supply, dug well 20 feet deep and 25 feet in diameter, to shallow Arkansas underflow, three 8-inch wells 105 feet deep to Dakota sandstone. Water pumped by two Deane compound 500 g. p. m. steam pumps from large well, and three Keystone deep-well pumps, 100 g. p. m. each, on small wells, discharging to standpipe 85,000 gallons capacity, 100 feet high. Keystone pumps are driven by motor, Deane pumps are driven by steam. Distribution system: 10-inch, 2300 feet; 8-inch, 6200 feet; 6-inch, 10,300 feet; 4-inch, 35,200 feet. Fire hydrants, 117; rental, $25 per year each. Consumers, 540; 99 per cent metered. Daily consumption, 150,000 gallons. Minimum rate, 50 cents per month.

WATER ANALYSIS.

Laboratory No. 5856. Source, Second street well; collected by M. Kronch; analysis completed July 26, 1913.

Laboratory No. 5994. Collected by W. Burgess; analysis completed September 2, 1913.

Bacterial Examination.	*5856*	*5994*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	100	100
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	5+
in five .1 cc. tubes	5—	1+ 4—
Chemical Analysis. Results in parts per million.		
Color	brown	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.8	.2
Nitrongen as free ammonia	.016	.004
Nitrogen as alb. ammonia	.03	.1
Nitrogen as nitrites	0	0
Nitrogen as nitrates	0	0
Total solids	471	1,365
Mineral Analysis.		
Cl	118	64
SO_4	92.56	711.7
HCO_3	180.6	202.5

Hardness group, 13; total solids group, 25.

LAWRENCE.

Population in 1910, 12,374. Plant was built by a private company in 1886. Source of supply consists of one large curb well, in the neighborhood of 30 feet in diameter and 30 feet deep; 24 driven points 6 inches in diameter, 50 feet in depth; and 500 feet of infiltration vitrified pipe laid 28 feet below the surface of the ground. The water is pumped by a Joseph Edwards Co. 4,000,000 gallon daily centrifugal pump into an open channel for aëration. This channel discharges into a large reservoir 336 feet x 143 feet x 12 feet deep, with side slopes of 1 to 1, with a capacity of 3½ million gallons. Water flows from this reservoir into a second reservoir 100 feet x 120 feet x 12 feet, with side slopes of 1 to 1, with a capacity of ¾ million gallons. This is for the purpose of aëration and sedimentation to remove iron. From either of these reservoirs the water may be pumped by a steam duplex compound pump with a capacity of 1000 g. p. m., or a duplex compound pump, with a capacity of 2100 g. p. m., directly into the mains. A standpipe 20 feet in diameter and 102 feet high, with a capacity of 250,000 gallons, uncovered.

The distribution system: 16-inch, 754 feet; 14-inch, 5344 feet; 12-inch, 2508 feet; 10-inch, 3683 feet; 8-inch, 9091 feet; 6-inch, 51,443 feet; 4-inch, 329,011 feet, cast-iron pipe. There are 173 fire hydrants, for which a rental of $30 and $31 per year is paid by the city. There are 2472 connections, business and domestic, with 270 dead. There are in the neighborhood of 1600 meters, or about 65 per cent. The daily consumption is close to 1,300,000 gallons.

The minimum rate charged for water is $7.50 per year, and the rate for 1000 gallons is 25 cents. Special rates are made to large consumers, varying from 5 cents per thousand gallons up.

WATER ANALYSIS.

Laboratory No. 6961. Source, well. Collected by F. W. B.; date of collection, September 1, 1914.

Bacterial Examination.	*6961*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	1,000	....
Agar, at 37°—24 hrs.	50	....
No. of positive fermentations:		
in one 10 cc. tube	1—	....
in five .1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	iron	....
Odor	none	....
Turbidity	50	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	.36	....
Nitrogen as alb. ammonia	.14	....
Nitrogen as nitrites	.001	....
Nitrogen as nitrates	none	....
Total solids	498	....
Mineral Analysis.		
SiO_2	37.4	....
$Fe_2O_3+Al_2O_3$	14	....
Ca	125.9	....
Mg	18.4	....
Na+K	37	....
Cl	36	....
SO_4	71.6	....
HCO_3	429	....

LEBANON.

Population in 1910, 731. Combined water and light plant built by city in 1907. Source of supply, three wells 19, 18, and 16 feet in diameter; 30, 26, and 47 feet deep. Fed by springs. Water pumped by double-acting, triplex 250 g. p. m. pump, driven by 25 hp. gas engine, discharging to an elevated tank 50,000-gallon capacity, on a tower 102 feet high. Distribution system: 6-inch, 21,000 feet; 4-inch, 3500 feet; 2-inch, 5000 feet; 2½-inch, 2400. Fire hydrants, 15; no rental. Consumers, 135; all metered. Daily consumption, 15,000 gallons. Minimum rate, $10 per year, 35 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5396. Collected by F. B. Meek; analysis completed November 25, 1912.

Laboratory No. 6190. Collected by J. L. Felton; analysis completed October 30, 1913.

Bacterial Examination.	*5396*	*6190*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	20	20
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.5	2.9
Nitrogen as free ammonia	0	.05
Nitrogen as alb. ammonia	.11	.136
Nitrogen as nitrites	0	trace
Nitrogen as nitrates	0	0
Total solids	434	495
Mineral Analysis.		
SiO_2	26.6	29.2
$Fe_2O_3+Al_2O_3$	1.2	1
Ca	128.2	133.6
Mg	11.9	14.5
Na+K	10.2	5
Cl	6.0	.4
SO_4	25.1	72.44
HCO_3	432.5	394.4

Hardness group, 7; total solids group, 8.

LIBERAL.

Population in 1910, 1716. Plant rebuilt by city in 1912. Source of supply, three wells 3, 4 and 6 inches in diameter, 180 feet deep. Water pumped by motor-driven pumps to 50,000-gallon tank on 100-foot tower. Distribution system: 8 miles of 8-inch pipe and smaller. Fire hydrants, 26; no rental. Consumers, 300. Daily consumption, 35,000 gallons. Rate, $1 for first 2000 gallons, 25 cents per thousand down to 20 cents; $1 for private houses, $1.50 houses with bath and toilet, etc.

WATER ANALYSIS.

Laboratory No. 4886. Collected by J. T. Gray; analysis completed April 11, 1912.

Laboratory No. 6098. Collected by J. Karon; analysis completed October 5, 1913.

Bacterial Examination.	*4886*	*6098*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	50,000	1,000
Presumptive tests for B. *coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	0	.5
Nitrogen as free ammonia	.04	0
Nitrogen as alb. ammonia	.024	.006
Nitrogen as nitrites	0	.004
Nitrogen as nitrates	2	3
Total solids	246	323
Mineral Analysis.		
SiO_2	40	19.2
$Fe_2O_3+Al_2O_3$	2.6	trace
Ca	53.3	54.6
Mg	27.2	23
Na+K	8	4
Cl	18	14
SO_4	56.6	52
HCO_3	217.2	202.5

Hardness group, 4; total solids group, 4.

LINCOLN.

Population in 1910, 1508. Plant built in 1906-'07 by the city. Source of supply, two 8-inch wells, 60 feet deep one 12-foot well, 50 feet deep. Water pumped by Deming, double-action 350 g. p. m. pump and three Foos pumps, 30 g. p. m. each, discharging into a 70,000-gallon standpipe 117 feet high, driven by a 125 hp. Ideal steam engine and an Ideal simple 75 hp. engine. Distribution system: 8-inch, 960 feet; 6-inch, 2890 feet; 4-inch, 11,420 feet; 2-inch, 4200 feet. Consumers, 281; all metered. Daily consumption, 160,000 gallons. Minimum rate, 50 cents per month. Rate for 1000 gallons, 15 cents.

WATER ANALYSIS.

Laboratory No. 5404. Collected by J. F. Meinhartz; analysis completed December 6, 1912.

Laboratory No. 6241. Collected by J. W. Meek; analysis completed November 21, 1913.

Bacterial Examination.	*5404*	*6241*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	1,000	5,500
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	5+
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.8	1.2
Nitrogen as free ammonia	0	.074
Nitrogen as alb. ammonia	.028	.054
Nitrogen as nitrites	.002	.0075
Nitrogen as nitrates	4	.01
Total solids	652	574

Mineral Analysis.

SiO_2	23	25.6
$Fe_2O_3+Al_2O_3$	1.2	5.6
Ca	172	131.9
Mg	10.9	9.8
Na+K	26.5	46
Cl	47.0	31
SO_4	173	110.9
HCO_3	347	378.5

Hardness group, 9; total solids group, 9.

LINDSBORG.

Population in 1910, 1939. Combined water and light plant built by city in 1905. Source of supply, four 6-inch wells 85 feet deep. Water pumped by two 200 g. p. m. pumps to 98,000-gallon standpipe. Distribution system not given. Fire hydrants, 41; rental, $3 per year each. Consumers, 361; 98 per cent metered. Daily consumption, 260,000 gallons. Minimum rate, 50 cents per month, with sliding scale of 20 cents to 8 cents per thousand.

WATER ANALYSIS.

Laboratory No. 4909. Collected by H. M. Blame; analysis completed April 22, 1912.

Laboratory No. 6167. Collected by A. Monson; analysis completed October 22, 1913.

Bacterial Examination.	*4909*	*6167*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	18,000	....
Agar, at 37° —24 hrs	11,200	4
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubs	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	5	0
Oxygen consumed	.61	0
Nitrogen as free ammonia	.144	.122
Nitrogen as alb. ammonia	.066	.086
Nitrogen as nitrites	.001	.005
Nitrogen as nitrates	0	0
Total solids	646	745

Mineral Analysis.

SiO_2	29.4	....
$Fe_2O_3+Al_2O_3$	12.8	....
Ca	157.5	....
Mg	30.7	....
Na+K	59	....
Cl	94.4	82
SO_4	180.4	....
HCO_3	401.6	395.5

Hardness group, 10; total solids group, 13.

LITTLE RIVER.

Population in 1910, 661. Plant built in 1915. Water is pumped from one well 10 feet in diameter by 46 feet deep, to a 50,000-gallon tank on a 100-foot tower, by two 5 x 8-inch deep-well triplex pumps, driven by 15 hp. oil engines. Distribution system: 6-inch, 4375 feet; 4-inch, 12,500 feet. Fire hydrants, 35. New supply 1915.

LOGAN.

Population in 1910, 725. Combined water and light plant built in 1906 by the city. Source of supply, two wells 16 feet in diameter and 20 feet deep. Prime mover, one 90 hp. steam fuel-oil engine. Water pumped by one vertical triplex single-acting 200-gallon-capacity and one double-acting power 334-gallon-capacity pump to a reservoir, 30,000 gallons capacity, 100 feet in height. Distribution system: 8-inch, 350 feet; 6-inch, 4284 feet; 4-inch, 4014 feet. Fire hydrants, 15; no rental. Consumers, 125; 90 per cent metered. Average daily consumption, 9000 gallons. Minimum rate, 50 cents per month. Rate for 1000 gallons, 15 cents.

WATER ANALYSIS.

Laboratory No. 5484. Collected by C. H. Hadden; analysis completed January 8, 1913.

Laboratory No. 6060. Collected by C. H. Hadden; analysis completed September 21, 1913.

Bacterial Examination.	*5484*	*6060*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	70	4,000
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubs	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	slightly green	0
Odor	0	0
Turbidity	slight	0
Oxygen consumed	4.3	.9
Nitrogen as free ammonia	.67	.21
Nitrogen as alb. ammonia	.146	.34
Nitrogen as nitrites	.001	.04
Nitrogen as nitrates	0	5.0
Total solids	529	574

Mineral Analysis.

SiO_2	32.2	43
$Fe_2O_3+Al_2O_3$	5.6	trace
Ca	135	155
Mg	19.3	23
Na+K	18.4	5
Cl	12	18
SO_4	60.4	58
HCO_3	459	493

Hardness group, 8; total solids group, 9.

LUCAS.

Population in 1910, 573. Combined water and light plant built in 1909 by the city. Source of supply, one well 30 feet in diameter and 36 feet deep, into 12 feet of sand and gravel. The prime movers at the plant consist of one 50 hp. oil engine and one 25 hp. oil engine, driving a 30 kw. generator. The water is pumped by a 350 g. p. m. deep-well triplex pump, against a total head of 200 feet into a 50,000-gallon covered tank on a 100-foot tower. Distribution system: 8-inch, 425; 6-inch, 4260; 4-inch, 11,050 feet pipe. There are 20 fire hydrants.

WATER ANALYSIS.

Laboratory No. 5370. Collected by Meinhertz; analysis completed November 11, 1912.

Laboratory No. 6012. Collected by G. W. Cook; analysis completed September 6, 1913.

Bacterial Examination.	*5370*	*6012*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	60	100
Presumptive tests for *B. coli*	—	—
Number of positive fermentations		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	5	0
Oxygen consumed	0	2.5
Nitrogen as free ammonia	.03	.002
Nitrogen as alb. ammonia	.04	0
Nitrogen as nitrites	0	0
Nitrogen as nitrates	1.5	.5
Total solids	1,120	1,000

Mineral Analysis.		
SiO_2	24.6	....
$Fe_2O_3+Al_2O_3$	2.6	....
Ca	106.3	....
Mg	18.8	....
Na+K	277.7	....
Cl	323	180
SO_4	119.3	120.8
HCO_3	447	459

Hardness group, 6; total solids group, 18.

LURAY.

Population in 1910, 341. Plant built by the city in 1912. Water is taken from two 8-inch wells 40 feet deep, cased with wrought iron. Water pumped by a 100 g. p. m. triplex pump, driven by a 12 hp. gasoline engine. into a 50,000-gallon tank on a 100-foot tower. Distribution system: 6-inch, 5300 feet; 4-inch, 7000 feet. Fire hydrants, 20.

WATER ANALYSIS.

Laboratory No. 6020. Collected by O. I. Stevenson; analysis completed September 9, 1913.

Laboratory No. 7074. Collected by J. B. Mack; analysis completed September 16, 1914.

Bacterial Examination.	*6020*	*7074*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	300
Agar, at 37° —24 hrs.	170	15
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	3—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	2.9	0
Nitrogen as free ammonia	0	.026
Nitrogen as alb. ammonia	0	.062
Nitrogen as nitrites	.01	0
Nitrogen as nitrates	.7	6
Total solids	1,068	1,099
Mineral Analysis.		
SiO_2	32.4	....
$Fe_2O_3+Al_2O_3$	3	....
Ca	128	....
Mg	22.5	....
Na+K	215	....
Cl	261	350
SO_4	181.4	172.8
HCO_3	381	417.5

Hardness group, 8; total solids group, 20.

LYONS.

Population in 1910, 2071. Plant built by city in 1885. Source of supply, four 8-inch wells, 60 feet deep. Water pumped by Deane duplex 417 g. p. m. pump, and a Fairbanks-Morse duplex 430 g. p. m. pump, discharging to reservoir 110,000-gallons capacity. Distribution system, about 6 miles of 4-, 6- and 8-inch cast iron pipe. Fire hydrants, 53; rentals, $45 per month. Consumers, 575; no meters. Daily consumption, 250,000 to 450,000 gallons. Flat rates, $6 to $17 per year.

NOTE.—Direct pressure is used.

WATER ANALYSIS.

Laboratory No. 5374. Collected by R. E. Turner; analysis completed November 11, 1912.

Laboratary No. 6094. Collected by R. E. Turner; analysis completed October 5, 1913.

Bacterial Examination.	*5374*	*6094*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	1,000	5
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	1+ 2—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.8	1.3
Nitrogen as free ammonia	.038	.014
Nitrogen as alb. ammonia	.038	.014
Nitrogen as nitrites	.003	.003
Nitrogen as nitrates	0	1.5
Total solids	425	412
Mineral Analysis.		
SiO_2	26.0	....
$Fe_2O_3+Al_2O_3$	.8	....
Ca	107.1	....
Mg	9.9	....
Na+K	27.3	....
Cl	54.4	50
SO_4	5.9	72.8
HCO_3	347	240.0

Hardness group, 6; total solids group, 6.

McCUNE.

Population in 1910, 736. Plant built in 1914. Source of supply, drilled well, 12 inches by 1290 feet. The water is first lifted into a surface reservoir and then pumped into a 50,000-gallon tank on a 100-foot tower. Distribution system: 8-inch, 1140 feet; 6-inch, 3230 feet; 4-inch, 9840 feet, cast-iron pipe, and 1500 feet of 2-inch pipe. Fire hydrants, 32. New supply 1915.

McPHERSON.

Population in 1910, 3546. Plant rebuilt by city in 1910. Combined water and light plant. Source of supply, one 10-inch, and one 7-inch, and one 6-inch well, 140 feet in depth. One Worthington fire pump, 1800 g. p. m. capacity, one steam driven Cook deep-well pump, and two motor-driven pumps discharge to standpipe 110 feet high, with capacity of 100,000 gallons. Distribution system: 10 miles of 6- and 4-inch pipe. Fire hydrants, 72; no rental. Consumers, 790; 97 per cent metered. Minimum rate, 55 cents per month. City pays water and electric department a flat rate of $660 per quarter for water and light.

WATER ANALYSIS.

Laboratory No. 5244. Collected by T. C. Miller; analysis completed September 26, 1912.

Laboratory No. 5905. Collected by M. Hawkinson; analysis completed August 8, 1913.

Bacterial Examination.	*5244*	*5905*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	22	60
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	1+ 4—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	c
Oxygen consumed	.4	0
Nitrogen as free ammonia	.022	.010
Nitrogen as alb. ammonia	.024	.004
Nitrogen as nitrites	0	0
Nitrogen as nitrates	.7	.7
Total solids	379	379
Mineral Analysis.		
SiO_2	28.8	49
$Fe_2O_3+Al_2O_3$	4.4	3.2
Ca	100.6	93
Mg	15.4	10.3
Na+K	11.9	22
Cl	32	38
SO_4	16.3	15.6
HCO_3	339	315

Hardness group, 6; total solids group, 6.

MADISON.

Population in 1910, 721. Combined water and light plant, built by city in 1913. Source of supply, one 5-foot and one 18-foot well, 33 feet deep. Water pumped by direct-acting deep-well pump, 200 g. p. m. capacity, and motor driven turbine, 150 g. p. m. capacity, discharging to a standpipe 12 x 60 feet; capacity, 50,000 gallons. Distribution system: 8-inch, 2040 feet; 6-inch, 2760 feet; 4-inch, 13,200 feet. Fire hydrants, 38; rental, $6 per year each. Consumers, 14; all metered. Minimum rate, 75 cents per month. Rate for thousand gallons, 35 cents.

WATER ANALYSIS.

Laboratory No. 6466. Collected by Chester E. Fellay; analysis completed February 24, 1914.

Bacterial Examination.	*6466*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	400	....
Agar, at 37°—24 hrs.	4	....
Presunptive tests for *B. coli*	—	....
No. of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	1.9	....
Nitrogen as free ammonia	.01	....
Nitrogen as alb. ammonia	.018	....
Nitrogen as nitrites	.03	....
Nitrogen as nitrates	4	....
Total solids	586	....

Mineral Analysis.

Cl	17.6	....
SO_4	51.52	....
HCO_3	484.6	....

Hardness group, 7; total solids group, 10.

MANHATTAN.

Population in 1910, 5722. Plant built by city in 1887. Source of supply, two 6-inch and four 4-inch wells, 40 feet deep, with Cook points. Water pumped by two motor-driven triplex pumps 500 and 1000 g. p. m. capacity, into a 750,000-gallon reservoir. Distribution system: 10-inch, 3728 feet; 8-inch, 9100 feet; 6-inch, 10,195 feet; 4-inch, 53,616 feet; and 2-inch, 34,536 feet. Fire hydrants, 94; no rental. Consumers, 1561; all metered. Daily consumption, 400,000 gallons. Minimum rate, $1.75 per quarter, with sliding scale from 20 cents to 10 cents.

NOTE.—New wells and extensions to the distribution system are under construction at present.

WATER ANALYSIS.

Laboratory No. 5574. Collected by J. C. Montgomery; analysis completed February 21, 1913.

Laboratory No. 5984. Collected by O. E. Noble; analysis completed August 29, 1913.

Bacterial Examination.	*5574*	*5984*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	6	4
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tube	5—	5—
in five .1 cc. tubes	5—	5—

Chemical Analysis.

Results in parts per million.

Color	greenish	brown
Odor	0	0
Turbidity	10	0
Oxygen consumed	.4	1.2
Nitrogen as free ammonia	.344	.3
Nitrogen as alb. ammonia	.078	.008
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	0	0
Total solids	542	640
Mineral Analysis.		
SiO_2	24	34
$Fe_2O_3+Al_2O_3$	7.4	1.8
Ca	139	53.3
Mg	23.1	23.7
Na+K	32	1.30
Cl.	18.4	25
SO_4	52.8	78.9
HCO_3	542	489.5

MANKATO.

Population in 1910, 1155. The source of supply is two wells 20 feet in diameter, 38 feet and 40 feet in depth, cased with rock laid in cement. Water is pumped by a 240 and 380 g. p. m. pump against a head of 190 feet, driven by a Fairbanks-Morse 32 hp. and 20 hp. respectively, distillate oil engine, into a standpipe 12 feet in diameter by 80 feet in height, uncovered. Distribution system: 8-inch, 2640 feet; 6-inch, 76 feet; 4-inch, 10,560 feet, cast-iron pipe; with 25 fire hydrants. There are 200 consumers; 60 per cent metered. Average daily consumption is 25,000 gallons. Minimum rate charged, 67 cents per month.

WATER ANALYSIS.

Laboratory No. 5571. Collected by D. J. Coy; analysis completed February 21, 1913.

Laboratory No. 5854. Collected by R. M. Canthorn; analysis completed July 26, 1913.

Bacterial Examination.	*5571*	*5854*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	14	100
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	3+ 2—
in five .1 cc. tubes	5—	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.7	1.15
Nitrogen as free ammonia	.032	.004
Nitrogen as alb. ammonia	.072	.074
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	3.5	2
Total solids	613	941

Mineral Analysis.		
SiO_2	26.6	36
$Fe_2O_3+Al_2O_3$	1.4	2.6
Ca	153	119
Mg	13.45	14
Na+K	15.2	125
Cl	34.4	40
SO_4	126.5	272.8
HCO_3	352	364

Hardness group, 8; total solids group, 17.

MARION.

Population in 1910, 1841. Combined water and light plant built in 1887 by the Marion City Water, Land, Electric and Power Co., purchased by the city in 1907. Source of supply is from one well 16 feet in diameter and 40 feet in depth, striking 3 feet of gravel in the bottom; and one well 20 feet in diameter and 48 feet in depth, striking 10 feet of coarse sand in the bottom. Water is pumped by two horizontal compound duplex steam pumps, 300 g. p. m., and a 250 g. p. m. triplex motor-driven; and one 400 g. p. m. motor-driven centrifugal pump. Electric power is furnished by a 125 hp. De La Vergne oil engine and one 80 hp. De La Vergne oil engine. There is a 70,000-gallon elevated tank on a 100-foot tower. Distribution system: 8-inch, 6600 feet; 6-inch, 7920 feet; 4-inch, 30,254 feet, cast-iron pipe. There are 42 fire hydrants, with no rental. There are 250 consumers, all metered. Average daily consumption is 300,000 gallons. Twenty cents per thousand is charged.

WATER ANALYSIS.

Laboratory No. 5447. Collected by G. E. Eye; analysis completed December 13, 1912.

Laboratory No. 6261. Collected by C. C. Jones; analysis completed December 10, 1913.

Bacterial Examination.	*5447*	*6261*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	2,000	190
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	5+	3+ 2—
in five .1 cc. tubes	....	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	5	0
Oxygen consumed	.9	3.33
Nitrogen as free ammonia	.03	.148
Nitrogen as alb. ammonia	.064	.268
Nitrogen as nitrites	0	.002
Nitrogen as nitrates	.5	0
Total solids	348	1,143
Mineral Analysis.		
Cl	7.2	18
SO_4	....	560
HCO_3	376	364

Hardness group, 18; total solids group, 21.

MARQUETTE.

Population in 1910, 715. Source of supply, one well 20 feet in diameter, 35 feet in depth. Water is pumped by two compound duplex steam pumps, against direct pressure. Distribution system consists of less than a mile of 4-inch and 6-inch pipe. There are 20 fire hydrants. A minimum rate of 50 cents per month is charged for water.

WATER ANALYSIS.

Laboratory No. 5375. Collected by H. E. Bruce; analysis completed November 11, 1912.

Laboratory No. 6507. Collected by C. A. Vann; analysis completed March 16, 1914.

Bacterial Examination.	*5375*	*6507*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	30
Agar, at 37°—24 hrs	250	21
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	0	c
Odor	0	0
Turbidity	0	c
Oxygen consumed	0	2.15
Nitrogen as free ammonia	.01	0
Nitrogen as alb. ammonia	.036	.036
Nitrogen as nitrites	0	.004
Nitrogen as nitrates	12	8
Total solids	541	553
Mineral Analysis.		
SiO_2	16.4	19.2
$Fe_2O_3+Al_2O_3$	2.2	.14
Ca	126.7	123.2
Mg	24.1	27
Na+K	5	67
Cl	26	31
SO_4	39.3	159.6
HCO_3	422.5	425

Hardness group, 8; total solids group, 9.

MEADE.

Population in 1910, 664. Plant built by city in 1910. Source of supply, one 12-inch and three 3-inch wells 176 to 293 feet in depth. Wells are semi-artesian and water is pumped to reservoir by an 80-cubic-foot-per-minute Gardner air compressor, capacity 130 gallons per minute. Pumped from reservoir to 55,000-gallon tank, on 100-foot tower, by a 350 g. p. m. Smith-Vaile pump. Distribution system: 8-inch, 1200 feet; 6-inch, 1300 feet; 4-inch, 6900 feet; 2-inch, 1800 feet. Fire hydrants, 18. Consumers, 140; all metered. Daily consumption, 60,000 gallons. Minimum rate, 75 cents per month. Rate for 1000 gallons, 30 cents.

WATER ANALYSIS.

Laboratory No. 4901. Collected by E. C. Innes; analysis completed May 19, 1912.

Laboratory No. 5942. Collected by E. C. Innes; analysis completed September 16, 1913.

Bacterial Examination.	*4901*	*5942*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	3,000	....
Agar, at 37° —24 hrs.	600	4
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis. Results in parts per million.		
Color	0	c
Odor	0	0
Turbidity	c	0
Oxygen consumed	.095	.1
Nitrogen as free ammonia	.002	.002
Nitrogen as alb. ammonia	.032	.002
Nitrogen as nitrites	0	.0005
Nitrogen as nitrates	1	1
Total solids	174	214
Mineral Analysis.		
SiO_2	18	21
$Fe_2O_3+Al_2O_3$	4.4	2.6
Ca	50.23	39
Mg	10.26	11
Na+K	6.5	22
Cl	8	10
SO_4	19.4	18.7
HCO_3	182.7	190.3

Hardness group, 3; total solids group, 2.

MEDICINE LODGE.

Population in 1910, 1229. Waterworks plant built by the city in 1889. Water is piped from the underflow of Elm creek, three and a half miles from the city, into a reservoir from which it is pumped by a steam pump or water turbine driven centrifugal pump into the mains.

WATER ANALYSIS.

Laboratory No. 5778. Analysis completed July 7, 1913.

Bacterial Examination.	*5778*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	8,000	....
Agar, at 37° —24 hrs.	Pos.	....
No. of positive fermentations:		
in one 10 cc. tube	+	....
in five 1 cc. tubes	5+	....
in five .1 cc. tubes	5+	....

Chemical Analysis.

Results in parts per million.

Turbidity	iron set.	....
Oxygen consumed	3.01	....
Nitrogen as free ammonia	.016	....
Nitrogen as alb. ammonia	.094	....
Nitrogen as nitrites	.005	....
Total solids	301	....
Mineral Analysis.		
Cl	30	....
HCO_3	236.5	....

MILTONVALE.

Population in 1910, 829. Combined water and light plant built by the city in 1913. Water is secured from two wells 10 inches in diameter, 65 feet and 99 feet in depth, respectively, cased with galvanized iron. A water bearing stratum of 14 feet of sand-rock is struck in the 65-foot well, and 70 feet in the 99-foot well. Water is pumped by two deep-well, 100 g. p. m., motor-driven pumps to a 60,000-gallon covered tank on a 100-foot tower. Pumps are each driven by 10 hp. motors. Power is furnished by two 50 hp. Fairbanks-Morse distillate oil engines. Distribution system: 6-inch, 5500 feet; 4-inch, 10,000 feet, cast-iron pipe; and 2-inch, 10,000 feet. There are 21 fire hydrants. There are 70 domestic consumers and 5 business consumers, all metered. Average daily consumption, 15,000 gallons. A minimum rate of 75 cents per month is charged for the first 3000 gallons, with a rate of 25 cents per thousand down to 10 cents for large amounts of water.

WATER ANALYSIS.

Laboratory No. 6288. Collected by S. G. Lacy; analysis completed December 20, 1913.

Laboratory No. 6458. Collected by S. G. Lacy; analysis completed February 24, 1914.

Bacterial Examination.	*6288*	*6458*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	220
Agar, at 37°—24 hrs	450	12
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	4+ 1—	3+ 2—
in five .1 cc. tubes	1+ 4—	1+ 4—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	15
Oxygen consumed	2.35	3.6
Nitrogen as free ammonia	.018	.014
Nitrogen as alb. ammonia	.028	0
Nitrogen as nitrites	trace	0
Nitrogen as nitrates	.4	.1
Total solids	365	312

Mineral Analysis.		
SiO_2	41	....
$Fe_2O_3+Al_2O_3$	5	....
Ca	40	....
Mg	9	....
Na+K	78	....
Cl	10	10
SO_4	59.65	18.51
HCO_3	278.5	278.5

Hardness group, 3; total solids group, 4.

MINNEAPOLIS.

Population in 1910, 1895. Waterworks plant was built by a private company in 1887, purchased by the city in 1907. The source of supply is from a tunnel 7 x 9 x 365 feet long through Dakota sandstone 60 feet below the surface. Water is pumped either by a 500 g. p. m. compound duplex steam pump or a simple duplex steam pump, with a capacity of 1000 g. p. m. against a 180-foot head into a 250,000-gallon standpipe, with a height of 80 feet. The distribution system: 10-inch, 1800 feet; 8-inch, 2000 feet; 6-inch, 2500 feet; 4-inch, 1000 feet, cast-iron pipe; and 2-inch, 5000 feet. Fire hydrants, 63; no rental. There are 500 consumers, all metered. The average daily consumption is about 300,000 gallons. Minimum rate charged for water is 50 cents per month, allowing 2000 gallons. A graduated rate of 25 cents to 5 cents is charged per thousand gallons in large amounts.

WATER ANALYSIS.

Laboratory No. 5284. Collected by R. E. Sutton; analysis completed October 24, 1912.

Laboratory No. 5999. Collected by R. E. Sutton; analysis completed September 3, 1913.

Bacterial Examination.	*5284*	*5999*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	10	15
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.2	.7
Nitrogen as free ammonia	.134	.002
Nitrogen as alb. ammonia	.044	.002
Nitrogen as nitrites	.001	.004
Nitrogen as nitrates	1.5	.3
Total solids	369	357

Mineral Analysis.

SiO_2	14.4	44.6
$Fe_2O_3+Al_2O_3$	2.6	2.2
Ca	66.4	33.6
Mg	14.8	15.6
Na+K	46.3	63
Cl	28	29
SO_4	54.8	46.89
HCO_3	280.5	239

Hardness group, 4; total solids group, 5.

MOLINE.

Population in 1910, 808. Plant built by city in 1913. Source of supply, one well 30 feet in diameter, and 34 feet deep. Infiltration galleries 400 feet in length constructed of 8 inch vitrified pipe lead into the well. Water pumped by a 150 g. p. m. vertical triplex pump, driven by 10 hp. motor. Fuel-oil Snow engine, 60 hp. is also available. Water pumped to 60,000-gallon tank on a 100-foot tower. Current purchased from the city plant. Distribution system: 8-inch, 1000 feet; 6-inch, 1925 feet; 4-inch, 6000 feet; 2-inch, 600 feet. Fire hydrants, 22; No rental. Minimum rate, $1 per quarter.

NOTE.—New plant.

MOUNDRIDGE.

Population in 1910, 626. Combined water and light plant built by city in 1909. Source of supply, four wells 6 to 20 feet in diameter, 20 to 200 feet in depth. From two small wells, two 4-cylinder force pumps discharge into a large well, capacity 25 gallons per minute each. From large well, a triplex pump discharges into a 30,000-gallon standpipe 110 feet high. Pumps driven by two Olds single-cylinder, 50 hp. each gas engines. Distribution system: 6-inch, 2600 feet; 4-inch, 7500 feet; 3-inch, 4200 feet; 1½-inch, 3000 feet. Fire hydrants, 24; no rental. Consumers, 110; all metered. Daily consumption, 12,000 to 15,000 gallons. Minimum rate, 50 cents per month. Rate for 1000 gallons, 30 cents to 20 cents.

WATER ANALYSIS.

Laboratory No. 5448. Collected by J. F. Regier; analysis completed December 13, 1912.

Laboratory No. 6437. Collected by J. F. Regier; analysis completed February 14, 1914.

Bacterial Examination.	*5448*	*6437*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	140
Agar, at 37° —24 hrs.	800	3
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	1+ 2—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	c
Oxygen consumed	1	1.1
Nitrogen as free ammonia	.036	.02
Nitrogen as alb. ammonia	.046	.06
Nitrogen as nitrites	.001	.003
Nitrogen as nitrates	2.5	1.5
Total solids	381	346

Mineral Analysis.

SiO_2	13.6	....
$Fe_2O_3+Al_2O_3$	1.2	....
Ca	84.7	....
Mg	13.9	....
Na+K	25	....
Cl	32	32
SO_4	39.7	41.14
HCO_3	288	259

Hardness group, 5; total solids group, 5.

MULBERRY.

Population in 1910, 997. Combined water and light plant built by city in 1913. Source of supply, one 10-inch well, 1000 feet deep. Water pumped from well by air lift 300 g. p. m., to surface reservoir, thence by a compound steam pump 350 g. p. m. capacity, and a single duplex 400 g. p. m. capacity pump, to 50,000-gallon tank on a 75-foot tower. Distribution system: 8-inch, 3200 feet; 6-inch, 1250 feet; 4-inch, 8100 feet. Fire hydrants, 25; no rental. Consumers, 143; 34 per cent metered. Daily consumption, 30,000 gallons. Minimum rate, 60 cents. Rate for 1000 gallons, 30 cents.

WATER ANALYSIS.

Laboratory No. 6202. Collected by J. Pedroja; analysis completed November 1, 1913.

Bacterial Examination.	*6202*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	[illegible]	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	1.09	....
Nitrogeen as free ammonia	.04	....
Nitrogen as alb. ammonia	.056	....
Nitrogen as nitrites	.0005	....
Nitrogen as nitrates	1.0	....
Total solids	625	....

Mineral Analysis.		
SiO_2	9.2	....
$Fe_2O_3+Al_2O_3$	.8	....
Ca	40	....
Mg	22	....
Na+K	180	....
Cl	160	....
SO_4	43.61	....
HCO_3	369	....

Hardness group, 4; total solids group, 11.

MULVANE.

Population in 1910, 1084. Plant built by city in 1910. Source of supply, five 8-inch wells, 30 feet deep. Water pumped to 50,000-gallon tank on 100-foot tower. Type of pumps not stated. Distribution system not given. Fire hydrants, 40; no rental. Consumers, 115; all metered. Daily consumption, 100,000 gallons. Minimum rate, 50 cents per month.

WATER ANALYSIS.

Laboratory No. 5226. Collected by R. P. Seyfer; analysis completed September 24, 1912.

Laboratory No. 6174. Collected by R. P. Seyfer; analysis completed October 25, 1913.

Bacterial Examination.	*5226*	*6174*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	50	300
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	1+ 4—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc tubes	2—	....
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	spicy	0
Turbidity	c	0
Oxygen consumed	1.9	1.8
Nitrogen as free ammonia	.038	.006
Nitrogen as alb. ammonia	.084	.076
Nitrogen as nitrites	.05	trace
Nitrogen as nitrates	7.5	3.5
Total solids	781	679
Mineral Analysis.		
SiO_2	21.2	....
$Fe_2O_3+Al_2O_3$	3.6	....
Ca	152	....
Mg	32.2	....
Na+K	29.1	....
Cl	50	36
SO_4	242	191.7
HCO_3	307.5	308

Hardness group, 8; total solids group, 12.

NATOMA.

Population in 1910, 407. Water is pumped from one well 16 feet in diameter by 46 feet deep, to a 50,000-gallon tank on an 80-foot tower by a 6 x 8-inch deep-well triplex pump. Distribution system: 8-inch, 150 feet; 6-inch, 3750 feet; 4-inch, 10,280 feet; 2-inch, 375 feet. Fire hydrants, 30. New supply 1915.

NEWTON.

Population in 1910, 7862. Plant built in 1897 by the city. Source of supply, ten wells 8 to 24 inches in diameter, depth 120 to 130 feet. Water pumped to surface reservoir by Layne & Bowler submerged centrifugal pumps. Pumped from reservoir by a Corliss cross-compound, crank-and-flywheel, 2,000,000-gallon-daily pump, and a Bates-Corliss and Allis-Chalmers steam pump. Water pumped to standpipe 30 x 120 feet, with a capacity of 634,000 gallons. Distribution system not given. Fire hydrants, 173; no rental. Consumers, 2204; all metered. Daily consumption, 1,200,000 gallons. Minimum rate, 50 cents per month, with sliding scale.

WATER ANALYSIS.

Laboratory No. 4890. Collected by Mayor; analysis completed May 11, 1912.

Laboratory No. 6009. Collected by Mayor; analysis completed September 5, 1913.

Bacterial Examination.	*4890*	*6009*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	liquefied	....
Agar, at 37° —24 hrs.	8	15
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.01	0
Nitrogen as free ammonia	.04	.006
Nitrogen as alb. ammonia	.06	.004
Nitrogen as nitrites	0	0
Nitrogen as nitrates	1	.5
Total solids	124	169
Mineral Analysis.		
SiO_2	27.4	30
$Fe_2O_3+Al_2O_3$	....	2.8
Ca	29.7	31.6
Mg	5.12	6
Na+K	9.15	24
Cl	9	10
SO_4	23.52	55.95
HCO_3	95	102.5

Hardness group, 1; total solids group, 1.

NICKERSON.

Population in 1910, 1195. Waterworks plant built by the city in 1914. There are three 10-inch wells, 70 feet in depth to the third Arkansas underflow, cased with perforated wrought and galvanized iron pipe into 12 feet of water-bearing sand and gravel. The power both for lighting the city and pumping the water is bought from the United Water, Gas and Electric Co., of Hutchinson. The water is pumped by a 70-80 g. p. m. motor-driven, triplex pump, against a 200-foot head, ordinarily, and a 400 g. p. m. motor-driven turbine is held in reserve. There is a 50,000-gallon covered tank on a 100-foot tower. Distribution system: 8-inch, 1880 feet; 6-inch, 3390 feet; 4-inch, 20,810 feet. There are 44 fire hydrants.

NOTE.—This plant is under construction.

WATER ANALYSIS.

Laboratory No. 6604. Source, well P. C. S.; analysis completed April 30, 1914.

Chemical Analysis. Results in parts per million.	*6604*	
Color	none	....
Odor	none	....
Turbidity	none	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	N. D.	....
Nitrogen as alb. ammonia	N. D.	....
Nitrogen as nitrites	none	....
Nitrogen as nitrates	none	....
Total solids	1,028	....
Mineral Analysis.		
Cl	347	....
SO_4	203	....
HCO_3	220	....

NORTON.

Population in 1910, 1787. Combined water and light plant built by city in 1888. Source of supply, five wells, 10 inches in diameter, 35 and 60 feet deep. Water pumped by two American deep-well pumps to standpipe and supply well, and by two Deane 1200 g. p. m. pumps. Prime movers, Deane cross-compound steam engine, 75 hp., Fairbanks,-Morse oil engine, 25 hp., and motor, 15 hp. Standpipe capacity 84,000 gallons, 100 feet high. Distribution system: 6-inch, 59 feet; 4-inch, 22,000 feet; 2-inch, 11,000 feet. Fire hydrants, 41; no rental. Consumers, 362; all metered. Daily consumption, 90,000 gallons. Minimum rate, $2 per quarter, with sliding scale from 24 cents to 10 cents.

WATER ANALYSIS.

Laboratory No. 5141. Collected by C. S. Kenney; analysis completed August 29, 1912.

Laboratory No. 6044. Collected by Hemphill; analysis completed September 13, 1913.

Bacterial Examination.	*5141*	*6044*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	1,140	20
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	2+ 3—	5—
in five .1 cc. tubes	5—	5—
in five .01 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	10
Oxygen consumed	.5	1.4
Nitrogen as free ammonia	.06	0
Nitrogen as alb. ammonia	.042	0
Nitrogen as nitrites	.001	.001
Nitrogen as nitrates	0	0
Total solids	400	399

Mineral Analysis.

SiO_2	41	29
$Fe_2O_3+Al_2O_3$	5.8	2.8
Ca	89.4	92
Mg	16.25	17
Na+K	35	24
Cl	21	14
SO_4	28	11.11
HCO_3	376	388

Hardness group, 5; total solids group, 6.

OAKLEY.

Population in 1910, 681. Combined water and light plant built by the city in 1910. The water is secured from several deep wells, pumped by either of two single-acting deep-well, 100 g. p. m. pumps into an elevated tank, with a capacity of 70,000 gallons on a 100-foot tower, covered. Prime movers for both water and light consist of 80 hp. oil engine and a 15 hp. gasoline engine. One of the pumps is driven by the gasoline engine and the other by a 7½ hp. motor. Distribution system: 8-inch, 2760 feet; 6-inch, 384 feet; 4-inch, 17,320 feet cast-iron pipe.

WATER ANALYSIS.

Laboratory No. 5308. Collected by C. A. Haskins; analysis completed October 20, 1912.

Laboratory No. 6102. Collected by Switzer; analysis completed October 11, 1913.

Bacterial Examination.	*5308*	*6102*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	5	30
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.

Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1	.55
Nitrogen as free ammonia	.006	.008
Nitrogen as alb. ammonia	.01	.032
Nitrogen as nitrites	.003	.004
Nitrogen as nitrates	2	1
Total solids	264	280

Mineral Analysis.

SiO_2	21.6	20
$Fe_2O_3+Al_2O_3$	3.8	2.4
Ca	55.5	53.7
Mg	17.2	18.1
Na+K	1.4	14
Cl	7	8
SO_4	13.1	29.4
HCO_3	225	254

Hardness group, 4; total solids group, 4.

OBERLIN.

Population in 1910, 1157. Combined water and light plant built by the city in 1905. Source of supply is four 4-inch wells, 65 feet in depth into 35 feet of water bearing stratum. A 125 hp. Corliss steam engine furnishes power. Water is pumped by a motor-driven pump against a head of 170 feet into a standpipe 12 feet in diameter and 100 feet high, not covered. Distribution system: 10-inch, 2200 feet; 8-inch, 2000 feet; 6-inch, 2200 feet; 4-inch, 11,000 feet cast-iron pipe. Fire hydrants, 27; no rental. Consumers, 114; all metered. A minimum rate of 50 cents per month is charged, with a rate of 15 cents for large amounts.

WATER ANALYSIS.

Laboratory No. 4948. Collected by W. W. Beyer; analysis completed May 8, 1912.

Laboratory No. 6207. Collected by Addlman; analysis completed October 31, 1913.

Bacterial Examination.	*4948*	*6207*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	....	12
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
in five .01 cc. tubes	3—	....

Chemical Analysis.
Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	10	0
Oxygen consumed	.45	0
Nitrogen as free ammonia	.23	.178
Nitrogen as alb. ammonia	.088	.05
Nitrogen as nitrites	0	trace
Nitrogen as nitrates	0	0
Total solids	330	500

Mineral Analysis.

SiO_2	31.6	36.8
$Fe_2O_3+Al_2O_3$	3.4	3.2
Ca	81.4	91
Mg	22.8	25.8
Na+K	35	60
Cl	18	20
SO_4	35.7	82.2
HCO_3	378	425

Hardness group, 6; total solids group, 8.

ONAGA.

Population in 1910, 759. Plant built in 1910 by the city. Water is secured from one well 15 feet in diamater and 33 feet in depth, cased with brick. Water is pumped by a vertical triplex 125 g. p. m. pump, against a head of 210 feet, into a standpipe 20 feet in diameter and 100 feet high, covered. Distribution system: 6-inch, 4244 feet; 4-inch, 12,708 feet cast-iron pipe. There are 23 fire hydrants.

WATER ANALYSIS.

Laboratory No. 5880. Collected by G. R. Jones; analysis completed August 4, 1913.

Bacterial Examination.	*5880*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	700	....
Presumptive tests for *B. coli*	—	....
No. of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.
Results in parts per million.

Color	0	....
Odor	0	....
Turbidity, clay and iron	150	....
Oxygen consumed	1.75	....
Nitrogen as free ammonia	.6	....
Nitrogen as alb. ammonia	.066	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	0	....
Total solids	546	....

Mineral Analysis.		
SiO_2	20.6	....
$Fe_2O_3+Al_2O_3$	13.6	....
Ca	98.6	....
Mg	33.8	....
Na+K	66	....
Cl	44	....
SO_4	58.7	....
HCO_3	495.3	....

Hardness group, 9; total solids group, 9.

OSBORNE.

Population in 1910, 1566. Plant built by private company in 1905. Purchased by city in 1912. Source of supply, well 12 feet in diameter, 50 feet deep. Water pumped by Deane steam pump, 30 hp., and motor-driven triplex 20 hp. pump discharging to elevated tank, 80,000 gallons capacity, on 100-foot tower. Records of distribution system destroyed. Fire hydrants, 32; no rental. Consumers, 300; 75 per cent metered. Minimum rate, 75 cents per month. Rate for 1000 gallons, 15 cents.

WATER ANALYSIS.

Laboratory No. 5605. Collected by A. C. Dilion; analysis completed February 27, 1913.

Laboratory No. 6804. Collected by J. H. Meiers; analysis completed July 6, 1914.

Bacterial Examination.	*5605*	*6804*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs	....	10
Agar, at 37°—24 hrs	....	10
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.9	0
Nitrogen as free ammonia	.004	.03
Nitrogen as alb. ammonia	.034	.054
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	4	5
Total solids	464	480
Mineral Analysis.		
SiO_2	23.2	....
$Fe_2O_3+Al_2O_3$	2.2	....
Ca	109	....
Mg	14.4	....
Na+K	31	....
Cl	19	20
SO_4	47.7	45.36
HCO_3	393	337.2

Hardness group, 6; total solids group, 8.

OXFORD.

Population in 1910, 730. Water plant built in 1914 by the city. Water supplied from three 15-inch wells 38 feet deep. Casing, patent cement type. Water found in 5-foot layer of gravel and sand. Prime mover, one Fairbanks horizontal gas engine, 15 hp. Water pumped by one 150 g. p. m. triplex pump. Standpipe, 50,000-gallon capacity, 100 feet high, covered. Distribution system: 6-inch, 1000 feet; 4-inch, 16,800 feet; 2-inch, 4000 feet. Fire hydrants, 29. Consumers, 36; all metered. Average daily consumption, 7500 gallons. Rate, 25 cents per thousand for first 5000 gallons, 20 cents per thousand for second 5000 gallons, and 15 cents per thousand for third 5000 gallons, 10 cents per thousand over 15,000 gallons.

WATER ANALYSIS.

Laboratory No. 6114. Collected by J. P. Lescer; analysis completed October 14, 1913.

Laboratory No. 6893. Collected by H. E. Whinery; analysis completed August 21, 1914.

Bacterial Examination.	*6114*	*6893*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°..24 hrs	150	5
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	3—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.7	.8
Nitrogen as free ammonia	.046	0
Nitrogen as alb. ammonia	.68	0
Nitrogen as nitrites	trace	.002
Nitrogen as nitrates	1	3.5
Total solids	306	362
Mineral Analysis.		
SiO_2	18.8	....
$Fe_2O_3+Al_2O_3$	1	....
Ca	61	....
Mg	13	....
Na+K	8	....
Cl	10	20
SO_4	4.11	trace
HCO_3	286	378.5

Hardness group, 4; total solids group, 5.

PEABODY.

Population in 1910, 1500. Water plant built in 1886 by the city. Water supplies from six wells, four 8 feet in diameter, one 20 feet in diameter and one 30 feet in diameter, depth from 27 to 30 feet. Casing, masonry and brick. Water pumped by one No. 9 Knowles steam pump 200 g. p. m. capacity, supplied from a return tubular steam boiler, 25 hp. Standpipe, 60,000-gallons capacity, 62 feet high, covered. Distribution

system: 8-inch, 3225 feet; 6-inch, 7575 feet; 4-inch, 6550 feet. Fire hydrants, 41; no rental. Customers, 200; all metered. Average daily consumption about 40,000 gallons. Minimum rate, 50 cents per month. Rate per thousand gallons, 30 cents for first 5000, 20 cents for next 20,000, 10 cents for all over 25,000 gallons.

WATER ANALYSIS.

Laboratory No. 5748. Collected by R. B. Roberts; analysis completed September 6, 1912.

Laboratory No. 6152. Collected by R. B. Roberts; analysis completed October 20, 1913.

Bacterial Examination.	*5748*	*6152*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	500,000	9,000
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	5+	5—
in five .1 cc. tubes	1+ 4—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1.7	.3
Nitrogen as free ammonia	0	.008
Nitrogen as alb. ammonia	0	.018
Nitrogen as nitrites	.001	trace
Nitrogen as nitrates	3	0
Total solids	864	733
Mineral Analysis.		
SiO_2	17.4	21.2
$Fe_2O_3+Al_2O_3$	2.2	.4
Ca	184.5	138
Mg	45.9	40
Na+K	14.1	41
Cl	26	20
SO_4	320	245.19
HCO_3	378	383.5

Hardness group, 11; total solids group, 13.

PHILLIPSBURG.

Population in 1910, 1302. Plant built by the city in 1890. Water is secured from two wells, one 24 feet in diameter and 26 feet in depth, and the other 30 feet in diameter and 30 feet in depth, pumped by a Deane steam pump into a standpipe 14 x 90 feet, covered. There is also a gasoline engine for power. Distribution system consists of four miles of 10-inch and smaller cast-iron pipe. There are 200 consumers. A minimum rate of $1 per month is made for water, with 40 cents for 1000 gallons additional.

NOTE.—Information secured in 1907.

WATER ANALYSIS.

Laboratory No. 5645. Collected by Bridegrooms; analysis completed April 7, 1913.

Laboratory No. 6100. Collected by S. L. Bracken; analysis completed October 11, 1913.

Bacterial Examination.	*5645*	*6100*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	550	100
Presumptive tests for *B. coli*.	—	+
Number of positive fermentations:		
in one 10 cc. tube.	—	+
in five 1 cc. tubes.	5—	5+
in five .1 cc. tubes.	5—	3+ 2—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	2.5	.65
Nitrogen as free ammonia	.006	0
Nitrogen as alb. ammonia	.062	.002
Nitrogen as nitrites	.003	.004
Nitrogen as nitrates	3	1.5
Total solids	536	402
Mineral Analysis.		
SiO_2	27.8	....
$Fe_2O_3+Al_2O_3$	4.6	....
Ca	67.2	....
Mg	14.7	....
Na+K	92.2	....
Cl	28	32
SO_4	75.6	52.96
HCO_3	378.5	305

Hardness group, 4; total solids group, 6.

PITTSBURG.

Population in 1910, 14,755. Plant built by private company in 1885. Purchased by city in 1911. Source of supply, five wells 6 to 15 inches in diameter, 1300 to 1500 feet in depth. Water pumped to surface reservoir by air lift and duplex steam pumps, and pumped to 100,000-gallon tank on a 100-foot tower by three compound duplex, one 2,000,000-gallon and two 1,500,000-gallon daily capacity pumps. Distribution system: 12-inch, 25,748 feet; 10-inch, 2244 feet; 8-inch, 24,814 feet; 6-inch, 109,782 feet; 4-inch, 39,800 feet; 2-inch, 24,331 feet. Fire hydrants, 266; rental per year, $45 each. Consumers, 3965; 25 per cent metered. Daily consumption, 1,250,000 gallons. Minimum rate, 80 cents, with sliding scale from 40 cents to 9 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5851. Collected by O. T. Jones; analysis completed July 26, 1913.

Bacterial Examination.	*5851*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	50	....
Presumptive tests for *B. coli*	+	....
Number of positive fermentations:		
in one 10 cc. tube	+	....
in five 1 cc. tubes	1+ 4—	....
in five .1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	....
Odor	H_2S	....
Turbidity	0	....
Oxygen consumed	1.3	....
Nitrogen as free ammonia	.096	....
Nitrogen as alb. ammonia	.036	....
Nitrogen as nitrites	.002	....
Nitrogen as nitrates	0	....
Total solids	329	....
Mineral Analysis.		
SiO_2	20	....
$Fe_2O_3+Al_2O_3$	.7	....
Ca	66.5	....
Mg	2	....
Na+K	141	....
Cl	88	....
SO_4	85.6	....
HCO_3	330	....

Hardness group, 3; total solids group, 5.

PLAINVILLE.

Population in 1910, 1090. Plant built by city in 1909. Water is secured from one well 10 feet in diameter and 54 feet deep, cased with brick. Water is pumped by a double-acting Smith-Vaile triplex pump. Distribution system: 4½ miles of 2-inch, 4-inch and 6-inch pipe. There are 26 fire hydrants. The connections are metered. Minimum rate charged for water is $6.50 per year. Rate for 1000 gallons, 15 cents.

WATER ANALYSIS.

Laboratory No. 5521. Analysis completed March 21, 1913.

Bacterial Examination.	*5521*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	250	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	c	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	1.2	....
Nitrogen as free ammonia	.016	....
Nitrogen as alb. ammonia	.036	....
Nitrogen as nitrites	.001	....
Nitrogen as nitrates	.5	....
Total solids	328	....

Mineral Analysis.

SiO_2	27	....
$Fe_2O_3+Al_2O_3$	1.6	....
Ca	86	....
Mg	8.17	....
Na+K	13.6	....
Cl	20	....
SO_4	17.6	....
HCO_3	278.5	....

Hardness group, 5; total solids group, 5.

PROTECTION.

Population in 1910, 390. Plant built in 1915. Water is pumped from one well 10 inches in diameter by 60 feet deep, by one double-acting motor-driven Keystone deep-well pump, to a 60,000-gallon tank on an 80-foot tower. Distribution system: 8-inch, 2070 feet; 6-inch, 3600 feet; 4-inch, 8700 feet. Fire hydrants, 22. New supply 1915.

PRATT.

Population in 1910, 3302. Plant built by city in 1884. Source of supply, 19 wells, 2 to 8 inches in diameter and 50 to 65 feet deep. Water pumped by two 500 g. p. m. Fairbanks-Morse oil engine pumps, discharging to one 100,000-gallon and one 50,000-gallon elevated tanks. Distribution system: 6-inch, 11,930 feet; 4-inch, 32,385 feet; 3-inch, 960 feet; 2-inch, 760 feet. Fire hydrants, 104; rental, $20 per year each. Consumers, 650; all metered. Daily consumption, 250,000 gallons.

WATER ANALYSIS.

Laboratory No. 4867. Collected by F. G. Haskins; Analysis completed February 3, 1912.

Laboratory No. 6173. Collected by city clerk; analysis completed October 25, 1913.

Bacterial Examination.	*4867*	*6173*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	....	3
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.77	1.75
Nitrogen as free ammonia	.048	0
Nitrogen as alb. ammonia	.052	.066
Nitrogen as nitrites	.004	trace
Nitrogen as nitrates	1.5	1
Total solids	305	356

Mineral Analysis.

SiO_2	....	21
$Fe_2O_3+Al_2O_3$	....	14
Ca	63.3	59
Mg	5.2	6
Na+K	57	52
Cl	90	79
SO_4	19.9	23.87
HCO_3	190.9	180.6

Hardness group, 5; total solids group, 3.

SABETHA.

Population in 1910, 1768. Combined water and light plant built by the city in 1910. Water is secured from five wells 6 inches in diameter and 140 feet deep, pumped by two 75 g. p. m. deep-well and three 150 g. p. m. deep-well pumps, discharging to a surface reservoir with a capacity of 200,000 gallons. Each deep-well pump is operated by a separate 5 hp. motor. There are also two American Well Works, one 100 g. p. m. and one 250 g. p. m. pumps, discharging into a 75,000-gallon tank on a 100-foot tower. Distribution system: 10-inch, 1000 feet; 8-inch 2500 feet; 6-inch 10,000 feet; 4-inch, 25,000 feet cast-iron pipe. There are 3000 feet of 2-inch pipe. There are 70 fire hydrants for which a rental of $35 each per year is charged. Consumers, 255; all metered. The daily consumption will average 95,000 gallons. The minimum rate charged for water is $6 per year, with graduated rates of from 15 cents to 30 cents for large amounts.

WATER ANALYSIS.

Laboratory No. 4874. Collected by E. E. Brocket; analysis completed April 3, 1912.

Laboratory No. 6104. Collected by G. H. Bunker; analysis completed October 14, 1913.

Bacterial Examination.	*4874*	*6104*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	25	....
Agar, at 37°—24 hrs	5	....
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	1—	5—
in five .1 cc. tubes	1—	5—
in five .01 cc. tubes	1—	....

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	0	.5
Nitrogen as free ammonia	.0012	.048
Nitrogen as alb. ammonia	.04	.086
Nitrogen as nitrites	0	trace
Nitrogen as nitrates	1	1
Total solids	433	603

Mineral Analysis.

SiO_2	142	23.2
$Fe_2O_3+Al_2O_3$	2	1.6
Ca	90.2	86
Mg	49.2	37
Na+K	29.2	76
Cl	25	28
SO_4	124.5	167.85
HCO_3	397	386

Hardness group, 7; total solids group, 10.

ST. JOHN.

Population in 1910, 1785. Plant built by city in 1910. Source of supply, six 8-inch wells, 50 feet deep. Water pumped by two Smith-Vaile triplex 350 g. p. m. pumps discharging to 50,000-gallon tank on 100-foot tower. Pumps operated by 40 hp. electric motor, furnished by St. John Mill and Power Co. Distribution system: 8-inch, 31,000 feet; 6-inch, 1585 feet; 4-inch, 23,133 feet; 2½-inch, 8671 feet. Fire hydrants, 43; rental, $24 per year each. Consumers, 268; 95 per cent metered. Daily consumption, average 56,000 gallons. Rate, 15 cents per thousand.

WATER ANALYSIS.

Laboratory No. 5483. Collected by Sievers; analysis completed January 7, 1913.

Laboratory No. 5965. Collected by Sievers; analysis completed August 22, 1913.

Bacterial Examination.	*5483*	*5965*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	200	....
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	....

Chemical Analysis.

Results in parts per million.

Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.7	0
Nitrogen as free ammonia	0	.008
Nitrogen as alb. ammonia	.006	.008
Nitrogen as nitrites	0	.003
Nitrogen as nitrates	2.5	1.2
Total solids	269	268

Mineral Analysis.		
SiO_2	19.25	19.5
$Fe_2O_3+Al_2O_3$	17	1.4
Ca	66.7	56.7
Mg	10.6	9.1
Na+K	8	28
Cl	20	30
SO_4	24.3	16.46
HCO_3	212.5	224.5

Hardness group, 4; total solids group, 3.

ST. MARYS.

Population in 1910, 1397. Combined water and light plant built by the city in 1910. Water is secured from four wells 4 inches in diameter and 60 feet deep, pumped by two 300 g. p. m. Wilcox pumps, against a head of 220 feet into a 75,000-gallon tank on a 60-foot tower. Distribution system consists of one-half mile of 10-inch, 1 mile of 8-inch, one-half mile of 6-inch and one mile of 4-inch cast-iron pipe. Fire hydrants, 58; no rental. Consumers, 160; all metered. The daily consumption is approximately 100,000 gallons. Minimum rate charged for water is 55 cents per month with a charge ranging from 40 cents to 10 cents per thousand gallons for large amounts.

WATER ANALYSIS.

Laboratory No. 4329. Collected by J. B. Bemarais; analysis completed March 28, 1911.

Laboratory No. 5701. Collected by A. Ulisson; analysis completed May 19, 1913.

Chemical Analysis. Results in parts per million.	*4329*	*5701*
Color	0	0
Odor	0	0
Turbidity	c	slight
Oxygen consumed	.36	1.2
Nitrogen as free ammonia	.124	.022
Nitrogen as alb. ammonia	.094	.022
Nitrogen as nitrites	.001	.25
Nitrogen as nitrates	5	6.0
Total solids	656	582
Mineral Analysis.		
SiO_2	....	23
$Fe_2O_3+Al_2O_3$	.5	5
Ca	....	85
Mg	....	26.8
Na+K	....	71
Cl	56	46
SO_4	83.4	96.3
HCO_3	451.98	376

Hardness group, 10; total solids group, 10.

SALINA.

Population in 1910, 9688. Waterworks plant owned by a private company. Water is taken from 33 wells ranging from 108 feet to 120 feet in depth, mostly 8 inches, with a few 24-inch Layne & Bowler wells. The original supply was secured from a sheet of shallow water through a dug well about 30 feet in depth. This has been discontinued and deeper water taken. Water is pumped by a Holly 250,000-gallon pump, Holly-Gaskill compound 1,500,000-gallon pump and Smith-Vaile 1,500,000-gallon pump. Reservoir held in reserve has a capacity of 250,000 gallons, with brick walls 60 feet in diameter and 12 feet deep. The distribution system consists of about 14 miles of cast-iron pipe. There were 118 fire hydrants in 1907 and 1050 consumers, all metered. The daily consumption is approximately 500,000 gallons.

WATER ANALYSIS.

Laboratory No. 5501. Collected by J. H. Bell; analysis completed January 9, 1913.

Laboratory No. 5962. Collected by C. E. Barker; analysis completed August 23, 1913.

Bacterial Examination.	*5501*	*5962*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	15	25
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	5—
in five .1 cc tubes	3—	5—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	4.2	.5
Nitrogen as free ammonia	.098	.002
Nitrogen as alb. ammonia	.092	.002
Nitrogen as nitrites	.0005	0
Nitrogen as nitrates	.3	.5
Total solids	707	719
Mineral Analysis.		
SiO_2	20.8	30.2
$Fe_2O_3+Al_2O_3$	2	.8
Ca	135	160
Mg	24.5	34.8
Na+K	52	45
Cl	46	44
SO_4	134.5	166.2
HCO_3	481.5	488

Hardness group, 8; total solids group, 12.

SCAMMON.

Population in 1910, 2233. Plant built by city in 1901. Source of supply, two 12-inch wells, 800 feet deep. Water pumped by two deep-well pumps, 100 g. p. m. capacity each. Driven by steam. Discharge to elevated tank, capacity 70,000 gallons on a 100-foot tower. Distribution system: 8-inch, 2500 feet; 6-inch, 800 feet; 4-inch, 15,000 feet; 2-inch, 10,000 feet. Fire hydrants, 30; rental, $56.50 per year each. Consumers, 364; 2 per cent metered. Daily consumption, 140,000 gallons. Flat rate, 50 cents per month. By meter, from 9 cents to 12 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5478. Collected by Cunningham; analysis completed December 31, 1912.

Laboratory No. 5933. Collected by I. P. Rafter; analysis completed August 14, 1913.

Bacterial Examination.	*5478*	*5933*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	10	....
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	slightly moldy	0
Turbidity	slight	0
Oxygen consumed	1.5	.3
Nitrogen as free ammonia	.208	.130
Nitrogen as alb. ammonia	.018	.002
Nitrogen as nitrites	0	0
Nitrogen as nitrates	0	0
Total solids	388	381
Mineral Analysis.		
SiO_2	8.4	16
$Fe_2O_3+Al_2O_3$	1.4	3.6
Ca	58.6	36
Mg	24.4	18
Na+K	48.4	95
Cl	26	31
SO_4	76	77.3
HCO_3	293	302.5

Hardness group, 5; total solids group, 6.

SCANDIA.

Population in 1910, 579. Plant built by city in 1911. Source of supply, two wells 10 feet in diameter and 25 feet deep. Water pumped by Deane triplex 350 g. p. m. pump, driven by 25 hp. Alamo gas engine. Pump discharges to 82,000-gallon tank on a 50-foot tower. Distribution system: 8-inch, 1300 feet; 6-inch, 1040 feet; 4-inch, 10,600 feet; 2-inch, 500 feet. Fire hydrants, 23; no rental. Consumers, 62; no meters. Minimum rate, 60 cents per month. Rate for 1000 gallons, 10 cents.

WATER ANALYSIS.

Laboratory No. 5004. Collected by A. Nelson; analysis completed June 7, 1912.

Laboratory No. 6147. Collected by J. W. Platner; analysis completed October 20, 1913.

Bacterial Examination.	*5004*	*6147*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	....	2,500
Presumptive tests for *B. coli*	+	—
Number of positive fermentations:		
in one 10 cc. tube	....	+
in five 1 cc. tubes	2+ 3—	5—
in five .1 cc. tubes	5—	5—
in five .01 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	c	0
Oxygen consumed	2	1.4
Nitrogen as free ammonia	0	.076
Nitrogen as alb. ammonia	0	.08
Nitrogen as nitrites	trace	.02
Nitrogen as nitrates	8	4
Total solids	768	761
Mineral Analysis.		
SiO_2	25.6	....
$Fe_2O_3+Al_2O_3$	2.4	....
Ca	149.5	....
Mg	17	....
Na+K	55.4	....
Cl	72	87
SO_4	122	134.95
HCO_3	406	388

Hardness group, 8; total solids group, 13.

SCOTT CITY.

Population in 1910, 1000. Plant built by city in 1914. Water supplied from two wells 12 inches in diameter and 82 feet deep. Casing, galvanized iron. Prime movers, one 60 hp. gas engine, one 35 hp. gas engine, using distillate oil. Water pumped by one Keystone duplex pump, 200 g. p. m. capacity, against 180-foot head. Standpipe, 50,000 gallons capacity, 118 feet in height, covered. Distribution system: 8-inch, 432 feet; 6-inch, 1776 feet; 4-inch, 16,450 feet; 2-inch, 5575 feet. Fire hydrants, 33; rental, $2.50 per month. Consumers, 21; all metered. Daily consumption, 25,000 gallons. Minimum rate, 75 cents per month. Rate per thousand gallons, 10 cents.

WATER ANALYSIS.

Laboratory No. 6117. Collected by J. F. Marsh; analysis completed October 15, 1913.

Bacterial Examination.	*6117*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	30,000	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	0	....
Oxygen consumed	1.25	....
Nitrogen as free ammonia	.006	....
Nitrogen as alb. ammonia	.132	....
Nitrogen as nitrites	.02	....
Nitrogen as nitrates	1	....
Total solids	457	....
Mineral Analysis.		
SiO_2	45	....
$Fe_2O_3+Al_2O_3$	20	....
Ca	47	....
Mg	14	....
Na+K	52	....
Cl	14	....
SO_4	32.09	....
HCO_3	288	....

Hardness group, 3; total solids group, 7.

SEDGWICK.

Population in 1910, 626. Waterworks plant built by city in 1913. Source of supply, two wells 15 inches in diameter and 48 feet deep, cased with cement casing into 25 feet of coarse sand and gravel. The current is purchased from the Arkansas Valley Interurban Company which drives two 15 hp. 220-volt electric motors, direct connected to two Smith-Vaile triplex pumps with a capacity of 7000 gallons per hour. Water is pumped into a 50,000-gallon covered tank on a 100-foot tower. Fire hydrants, 31. Consumers, 60; all metered. A minimum rate of 75 cents per month allows 3000 gallons. A rate for 1000 gallons over this is 25 cents.

WATER ANALYSIS.

Laboratory No. 6983-208. Source, city supply; analysis completed September 12, 1914.

Bacterial Examination	*6983-208*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	6	....
Presumptive tests for *B. coli*	Neg.	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Oxygen consumed	0	....
Nitrogen as free ammonia	.03	....
Nitrogen as alb. ammonia	.044	....
Nitrogen as nitrites	.02	....
Nitrogen as nitrates	2.0	....
Total solids	367	....
Mineral Analysis.		
SiO_2	20.4	....
$Fe_2O_3+Al_2O_3$	0	....
Ca	86.4	....
Mg	16.0	....
Cl	14	....
SO_4	34.97	....
HCO_3	298	....

SENECA.

Population in 1910, 1806. Water and light plant built in 1896 by city. Water supplied from springs flowing through two miles of gravity flow line to well 30 feet in diameter by 60 feet deep. Prime movers, one Corliss engine and one Erie high speed oil engine, type and capacity of pumps not given. Standpipe, 100 feet high by 12 feet in diameter, not covered. Distribution system, 10-inch, 2900 feet; 8-inch, 2900 feet; 6-inch, 500 feet; 4-inch, 37,500 feet. Fire hydrants, 125; hydrants and street lights, $125 per month charge. Consumers, 350. Average daily consumption, 120,000 gallons.

WATER ANALYSIS.

Laboratory No. 5328. Collected by Doctor Brewer; analysis completed November 8, 1912.

Laboratory No. *6150.* Collected by D. Minor; analysis completed October 20, 1913.

Bacterial Examination.	*5328*	*6150*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	....	80
Presumptive tests for *B. coli*	—	—
No. of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	0
Nitrogen as free ammonia	.016	.048
Nitrogen as alb. ammonia	0	.038
Nitrogen as nitrites	.001	.0005
Nitrogen as nitrates	1	.5
Total solids	345	344

Mineral Analysis.		
SiO_2	24.6	30.8
$Fe_2O_3+Al_2O_3$	1.2	4
Ca	77.5	81
Mg	20.2	23.7
Na+K	18.6	50
Cl	2.6	6
SO_4	12.2	90.5
HCO_3	369	374

Hardness group, 5; total solids group, 5.

SHARON SPRINGS.

Population in 1910, 350. The source of supply is from a brick-cased dug well 12 feet in diameter and 41 feet deep. The water is pumped by Fairbanks deep-well pump into a steel pressure tank, having a capacity of approximately 16,000 gallons. Distribution system: 6-inch, 800 feet; 4-inch, 3500 feet; 2-inch, 950 feet. Consumers, 125; 100 per cent metered. Minimum monthly charge, $1. Rate per 1000 gallons, from 50 to 20 cents.

WATER ANALYSIS.

Laboratory No. 5290. Collected by W. S. Scott; analysis completed October 10, 1912.

Laboratory No. 6294. Collected by W. L. Scott; analysis completed December 20, 1913.

Bacterial Examination.	*5290*	*6294*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	20	5
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	woody	0
Turbidity	0	0
Oxygen consumed	0	1
Nitrogen as free ammonia	.022	.01
Nitrogen as alb. ammonia	.05	.016
Nitrogen as nitrites	0	trace
Nitrogen as nitrates	0	.4
Total solids	486	541
Mineral Analysis.		
SiO_2	34.2	35.2
$Fe_2O_3+Al_2O_3$	1.4	.4
Ca	59.2	71
Mg	22.2	26
Na+K	86	82
Cl	10.8	14
SO_4	77	102
HCO_3	400.5	407.8

Hardness group, 4; total solids group, 9.

SIMPSON.

Population in 1910, 211. A municipal water system is under construction at the present time. The water will be pumped from a well 8 feet in diameter and 45 feet deep to a fifty-thousand-gallon tank on a 100-foot tower by a 6-inch by 8-inch deep-well triplex pump. Distribution system: 6-inch, 700 feet; 4-inch, 5250 feet, cast-iron pipe; and 2125 feet of 2-inch pipe. Fire hydrants, 18. New supply 1915.

SMITH CENTER.

Population in 1910, 1292. Plant built originally in 1890. Rebuilt in 1905 and again in 1913. Originally, the supply was furnished by a dug well 25 feet in diameter and 20 feet deep, about 1½ miles southeast of the city on the Rock Island tracks. This well secures its water by seepage through a layer of sand and gravel from the Rock Island lake. The source of supply has been changed by the construction of an intercepting gallery about 8 ft. by 12 ft., 185 feet long, intercepting the seepage from this lake. The water is pumped from the infiltration gallery by a Deming 8½-inch by 8-inch triplex pump, belt connected to a 30 hp. two-cylinder Dempster engine and an 8-inch by 10-inch direct-connected Gould pump is saved for additional equipment. Water is pumped into a 93,000-gallon standpipe in the city. The distribution system consists of two miles of 6-inch pipe, including flow line to tank; one-half mile of 4-inch, and a half mile of 2-inch pipe. There are 150 consumers.

WATER ANALYSIS.

Laboratory No. 4637. Collected by Dr. Slagle; analysis completed October 3, 1911.

Laboratory No. 6064. Collected by G. T. Walker; analysis completed September 23, 1913.

Bacterial Examination.	*4637*	*6064*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	....	14,000
Presumptive tests for *B. coli*	....	+
Number of positive fermentations:		
in one 10 cc. tube	....	+
in five 1 cc. tubes	....	5+
in five .1 cc. tubes	....	5+
Chemical Analysis. Results in parts per million.		
Color	0	....
Odor	0	....
Turbidity	15	....
Oxygen consumed	2.23	....
Nitrogen as free ammonia	.056	....
Nitrogen as alb. ammonia	.244	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	1.5	....
Total solids	534	....
Mineral Analysis.		
$Fe_2O_3+Al_2O_3$	5	....
Cl	13	....
SO_4	71.24	....
HCO_3	396.1	....

STAFFORD.

Population in 1910, 1927. Combined water and light plant owned by the city. Original waterworks plant built in 1907, rebuilt in 1911. Light plant purchased in 1911 and combined. The source of supply consists of one large well, the original supply, with sand points driven in the bottom to a depth of 55 feet. There are also four small wells 8 inches in diameter and 55 feet deep into a stratum of 10 feet of gravel. Power is furnished by a Corliss 125 hp. steam engine, using coal for fuel. Water is pumped by a Worthington compound duplex 500 g. p. m. steam pump. There is also a Pratt Iron Works, 2-stage centrifugal 600 g. p. m. pump, direct connected to a 50 hp. motor. Water is pumped into a 75,000-gallon covered tank on a 100-foot tower. Distribution system: 8-inch, 3940 feet; 6-inch, 6080 feet; 4-inch, 22,750 feet cast-iron pipe. There are 45 fire hydrants. Minimum rate charged for water is 75 cents per month with a rate of 35 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 6019. Collected by R. M. Boyd; analysis completed September 9, 1913.

Laboratory No. 7014. Collected by city engineer; analysis completed September 23, 1914.

Bacterial Examination.	*6019*	*7014*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	18	10
Presumptives tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	3—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.2	.5
Nitrogen as free ammonia	.006	.01
Nitrogen as alb. ammonia	.008	.046
Nitrogen as nitrites	.0005	0
Nitrogen as nitrates	.5	trace
Total solids	435	440
Mineral Analysis.		
Cl	103	10
SO_4	35.4	27.98
HCO_3	241.5	374

Hardness group, 4; total solids group, 7.

SPEARVILLE.

Population in 1910, 576. Waterworks under construction. Supply will be pumped from two 8-inch wells, approximately 100 feet deep, to a fifty-thousand-gallon tank on a 100-foot tower, by a 6-inch by 8-inch deep-well triplex pump, capacity 135 g. p. m. Distribution system: 8-inch, 1100 feet; 6-inch, 1632 feet; 4-inch, 20,600 feet cast-iron pipe; and 800 feet of 2-inch pipe. Fire hydrants, 18. New supply 1915.

STERLING.

Population in 1910, 2133. Plant built by city in 1887. Source of supply, eight wells 6 inches in diameter by 30 feet deep. Water pumped against direct pressure by a Deane triple-expansion condensing steam engine with a capacity of 1,500,000 gallons daily, and two Dean compound duplex steam pumps with a capacity of 500,000 gallons each daily. Distribution system: 8-inch, 4146 feet; 6-inch, 6748 feet; 4-inch, 12,038 feet; 2-inch, 13,804 feet. Fire hydrants, 45; no rental. Consumers, 450; all metered. Average daily consumption, 137,000 gallons.

WATER ANALYSIS.

Laboratory No. 5477. Collected by city clerk; analysis completed January 3, 1913.

Laboratory No. 6039. Collected by A. Cavin; analysis completed September 13, 1913.

Bacterial Examination.	*5477*	*6039*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	1,000	160
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	+	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1	.14
Nitrogen as free ammonia	.006	0
Nitrogen as alb. ammonia	.004	0
Nitrogen as nitrites	.0005	.001
Nitrogen as nitrates	3	2.5
Total solids	875	849
Mineral Analysis.		
SiO_2	13.2	13.6
$Fe_2O_3+Al_2O_3$	1	.6
Ca	114.6	111
Mg	25.3	27
Na+K	143	96
Cl	210	180
SO_4	150.5	131
HCO_3	305	317.5

Hardness group, 7; total solids group, 15.

STOCKTON.

Population in 1910, 1317. Plant built by city in 1887. Water and light plant combined. Source of supply, one well 16 feet in diameter, 32½ feet deep. Water taken from six 4-inch sand points 4 feet long and Cook strainer points 17 feet below bottom of well. Water pumped by compound steam duplex pump, 200 g. p. m. capacity, and a single-acting triplex 300 g. p. m. capacity pump, discharging to 85,000-gallon standpipe. Prime movers, 100 hp. De La Vergne oil engine and a 60 hp. St.

Marys Machine Co. oil engine. Distribution system: 8-inch, 3600 feet; 4-inch, 15,800 feet; 2-inch, 12,200 feet. Fire hydrants, 33; no rental. Consumers, 355. Average consumption, 150,000 gallons. Minimum rate, $5 per year. Meter rental, $1 per year; rate for 1000 gallons, 15 cents.

WATER ANALYSIS.

Laboratory No. 5373. Collected by F. A. Chipman; analysis completed November 18, 1912.

Laboratory No. 6080. Collected by F. A. Chipman; analysis completed September 30, 1913.

Bacterial Examination.	*5373*	*6080*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	150	500
Presumptive tests for *B. coli*	—	+
No. of positive fermentations:		
in one 10 cc. tube	—	+
in five 1 cc. tubes	3—	1+ 4—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	yellowish tint	0
Odor	0	0
Turbidity	10	0
Oxygen consumed	2.34	2.5
Nitrogen as free ammonia	.063	.168
Nitrogen as alb. ammonia	.072	.072
Nitrogen as nitrites	trace	.004
Nitrogen as nitrates	0	5
Total solids	641	568
Mineral Analysis.		
SiO_2	30.6	....
$Fe_2O_3+Al_2O_3$	3.8	....
Ca	124.1	....
Mg	20.1	....
Na+K	55	....
Cl	54.4	18
SO_4	165.5	165.8
HCO_3	322.5	325

Hardness group, 7; total solids group, 9.

STRONG CITY.

Population in 1910, 762. Waterworks plant built by city in 1914. Source of supply, one well 15 feet in diameter and 52 feet deep, cased with concrete and brick into water-bearing stratum. The power is furnished by one 4-cylinder 15 hp. distillate Alamo oil engine, driving a 150 g. p. m. triplex pump. Water is pumped to a 69,000-gallon reinforced concrete reservoir 15 feet in depth and 30 feet in diameter, covered, located on an adjacent hill. The distribution system: 8-inch, 2200 feet; 6-inch, 5100 feet; 4-inch, 8000 feet; 2-inch, 5000 feet. A 6-inch line from the distribution system to the reservoir is of 6-inch steel pipe. There are 27 fire hydrants and 30 consumers, all metered. A minimum rate of 20 cents per thousand is charged for water.

SYLVAN GROVE.

Population in 1910, 464. Plant built in 1911 by the city. Source of supply, two 12-inch wells, 58 feet deep. Water pumped by Smith-Vaile triplex 300 g. p. m. capacity pump, operated by electric motor, from 50 hp. Fairbanks-Morse oil engine, or from a single cylinder Fairbanks-Morse engine. Pump discharged to 50,000-gallon tank on a 100-foot tower. Distribution system: 6-inch, 2800 feet; 4-inch, 8500 feet. Fire hydrants, 13; no rental. Consumers, 136; all metered. Daily consumption 38,000 gallons. Minimum rate $1. Rate for 1000 gallons, 25 cents.

WATER ANALYSIS.

Laboratory No. 6300. Collected by H. S. Busick; analysis completed December 19, 1913.

Bacterial Examination.	*6300*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	3	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—	....
Chemical Analysis.		
Results in parts per million.		
Nitrogen as nitrates	1.0	....
Total solids	415	....
Mineral Analysis.		
SiO_2	16.4	....
$Fe_2O_3 + Al_2O_3$	2	....
Ca	78	....
Mg	11	....
Na + K	47	....
Cl	24	....
SO_4	22	....
HCO_3	349	....

Hardness group, 4; total solids group, 6.

SYRACUSE.

Population in 1910, 1126. Plant built in 1911 by the city. Combined water and light plant. Source of supply, one well 10 inches in diameter, 482 feet deep. From Dakota sandstone. Water pumped by Smith-Vaile triplex 375 g. p. m. pump, and Keystone double-acting, 110 g. p. m. pump, motor driven. Pumps discharge to surface reservoir, 105,000 gallons capacity, and 75,000-gallon elevated tank on 105-foot tower furnishes pressure. Prime mover, 80 hp. Fairbanks-Morse distillate-oil engine. Distribution system: 8-inch, 1800 feet; 6-inch, 5500 feet; 4-inch, 10,000 feet; 2-inch, 650 feet. Fire hydrants, 27; rental, $30 per year. Consumers, 150; all metered. Daily consumption, 30,000 gallons. Rate, $1.50 per month; 15 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5466. Collected by C. A. Haskins; analysis completed January 21, 1913.

Laboratory No. 5879. Collected by A. Gale; analysis completed August 4, 1913.

Bacterial Examination.	*5466*	*5879*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	3,000	150
Presumptive tests for *B. coli*	—	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	3—	1+ 4—
in five .1 cc. tubes	3—	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	15	150
Oxygen consumed	1	.95
Nitrogen as free ammonia	.022	.75
Nitrogen as alb. ammonia	.012	.004
Nitrogen as nitrites	0	.05
Nitrogen as nitrates	.5	.5
Total solids	922	1,224
Mineral Analysis.		
SiO_2	14.4	19
$Fe_2O_3+Al_2O_3$	5.4	.8
Ca	29	13
Mg	8.5	8.5
Na+K	261	390
Cl	22	24
SO_4	400	581.2
HCO_3	264	359

Hardness group, 2; total solids group, 22.

TOPEKA.

Population in 1910, 43,684. Plant built in 1881 by private company. Purchased by city in 1905. Source of supply, thirty-six 6-inch to 8-inch wells, 30 feet deep; one dug well, 48 feet in diameter and 45 feet deep; two dug wells, 60 feet in diameter and 45 feet deep. Water pumped direct by two horizontal cross-compound Gaskill steam pumps, capacity 3470 g. p. m. each, and one Allis-Chalmers 5555 g. p. m. horizontal cross-compound pump. Distribution system: 18-inch, 20,644 feet; 16-inch, 1095 feet; 14-inch, 3138 feet; 12-inch, 36,470 feet; 10-inch, 10,801 feet; 8-inch, 22,781 feet; 6-inch, 143,516 feet; 4-inch, 125,108 feet; 2-inch, 3000 feet. Fire hydrants, 609. Under levy, $15,000 per year is raised for fire hydrants, or about $24.75 each. Consumers, 7000; all metered. Average daily consumption, 2,800,000 gallons. Minimum rate, 40 cents per month, with sliding scale from 35 cents to 9 cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 4871. Collected by J. Shaw; analysis completed March 21, 1912.

Laboratory No. 6148. Collected by J. Shaw; analysis completed October 20, 1913.

Bacterial Examination.	*4871*	*6148*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	....	16
Presumptive tests for *B. coli*	....	—
Number of positive fermentations:		
in one 10 cc. tube	....	—
in five 1 cc. tubes	....	5—
in five .1 cc. tubes	....	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	3.30	1.5
Nitrogen as free ammonia	.088	.102
Nitrogen as alb. ammonia	.226	.082
Nitrogen as nitrites	.004	0
Nitrogen as nitrates	0	0
Total solids	302	619
Mineral Analysis.		
SiO_2	11.6	22
$Fe_2O_3+Al_2O_3$	9.8	3.6
Ca	62.2	52
Mg	12.58	17.6
Na+K	33	100
Cl	56	143
SO_4	61.05	6.58
HCO_3	224.8	256

Hardness group, 4; total solids group, 4.

TURON.

Population in 1910, 572. Combined water and light plant built by the city in 1913. Source of supply, one well 8 inches in diameter and 75 feet in depth. Prime mover consists of 70 hp. steam boiler, driving a 50 hp. steam engine, which, in turn, drives a 37½ K. V. A. generator. The water is pumped by three 50 g. p. m. steam pumps against a total head of 180 feet, into a 50,000-gallon elevated tank on a 100-foot tower. Distribution system: 6-inch, 1500 feet; 4-inch, 8050 feet; 2-inch, 3630 feet. There are 23 fire hydrants.

WATER ANALYSIS.

Laboratory No. 7144. Source, well; collected by R. A. Greeson; analysis completed November 10, 1914.

Bacterial Examination.	*7144*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	8	....
Agar, at 37°—24 hrs.	5	....
Presumptive tests for *B. coli*	—	....
Number of positive fermentations:		
in five 1 cc. tubes	5—	....
in five .1 cc. tubes	5—q	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	none	....
Odor	none	....
Turbidity	10	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	.074	....
Nitrogen as alb. ammonia	.072	....
Nitrogen as nitrites	none	....
Nitrogen as nitrates	1.0	....
Total solids	803	....
Mineral Analysis.		
Cl	320	....
SO_4	38	....
HCO_3	246.5	....

UDALL.

Population in 1910, 330. Water works plant constructed by the city in 1905. Source of supply consists of one well 5 feet in diameter and 100 feet deep, into a limstone spring. A gasoline engine drives a single-acting deep-well pump, discharging into a 30,000-gallon elevated tank on a 70 foot tower. Distribution system consists of 500 feet of 4-inch pipe. There are 16 fire hydrants. A minimum rate of 50 cents per month is charged for water, with a rate of 50 cents per thousand for large amounts.

WATER ANALYSIS.

Laboratory No. 7236. Source, C. S.; analysis completed December 15, 1914.

Bacterial Examinations.	*7236*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	Liquified	....
Agar, at 37°—24 hrs.	160	....
Presumptive tests for *B. coli*	Neg.	....
No. of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	0	....
Odor	0	....
Turbidity	0	....
Nitrogen as free ammonia	.054	....
Nitrogen as alb. ammonia	.074	....
Nitrogen as nitrites	0	....
Nitrogen as nitrates	.1	....
Total solids	810	....
Mineral Analysis.		
Cl	64	....
SO_4	230.38	....
HCO_3	397.8	....

VALLEY FALLS.

Population in 1910, 1129. Original waterworks plant was built on the bank of Grasshopper creek and secured water from a well, which also had a direct connection to the creek. In 1910, the source of the city supply was changed to a series of springs four miles out of town. The water is collected in three spring cribs and flows by gravity through 18,360 feet of 4-inch cast iron pipe flow line to a 311,000-gallon reservoir in the city. From here it is pumped by two 250 g. p. m. triplex pumps, belt connected to a 20 hp. gasoline engine, against a head of 150 feet into a 30 x 20-foot standpipe. Distribution system: 6-inch, 6000 feet; 4-inch, 12,600 feet cast-iron pipe, in addition to 18,360 feet of 4-inch cast-iron pipe in the flow line. There are 27 fire hydrants.

WATER ANALYSIS.

Laboratory No. 5524. Source, springs; collected by G. Harmon; analysis completed February 18, 1913.

Bacterial Examination.	*5524*	
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	15	....
Number of positive fermentations:		
in one 10 cc. tube	—	....
in five 1 cc. tubes	5—	....
Chemical Analysis. Results in parts per million.		
Color	none	....
Odor	none	....
Turbidity	.5	....
Oxygen consumed	.7	....
Nitrogen as free ammonia	.004	....
Nitrogen as alb. ammonia	.016	....
Nitrogen as nitrites	.001	....
Nitrogen as nitrates	5	....
Total solids	301	....
Mineral Analysis.		
SiO_2	25.2	....
$Fe_2O_3+Al_2O_3$	3.8	....
Ca	68.4	....
Mg	5.9	....
Cl	4.0	....
SO_4	10.8	....
HCO_3	249	....

WA KEENEY.

Population in 1910, 900. Water and light plant built in 1909 by the city. Water supplied from four wells, 6 inches in diameter by 34 feet deep. Prime mover, 25 hp. oil engine, using distillate. Water pumped by motor-driven pump, size not specified, to a standpipe 130 feet high, 75,000-gallon capacity, covered. Distribution system not specified. Fire hydrants, 40; no rental. Consumers, 121; all metered. Average daily consumption, 100,000 gallons. Rate charged for thousand gallons, 15 cents. Minimum monthly charge, 50 cents.

WATER ANALYSIS.

Laboratory No. 5524. Collected by G. Hannan; analysis completed February 18, 1913.

Laboratory No. 6165. Collected by H. Long; analysis completed October 22, 1913.

Bacterial Examination.	*5524*	*6165*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	15	600
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
Chemical Analysis.		
Results in parts per million.		
Color	c	0
Odor	0	0
Turbidity	5	0
Oxygen consumed	.7	1.9
Nitrogen as free ammonia	.004	.012
Nitrogen as alb. ammonia	.016	.34
Nitrogen as nitrites	.001	0
Nitrogen as nitrates	5	2
Total solids	301	258
Mineral Analysis.		
SiO_2	25.2	33
$Fe_2O_3+Al_2O_3$	3.8	.8
Ca	68.4	61
Mg	5.95	10
Na+K	15.6	33
Cl	4	8
SO_4	10.8	7.82
HCO_3	259	300.5

Hardness group, 3; total solids group, 3.

WAKEFIELD.

Population in 1910, 574. Plant built in 1910 by city. Source of supply, two 16-foot wells, 54 feet deep. Water pumped by Deming triplex pump to 30,000-gallon tank on 100-foot tower. Driven by Alamo gasoline engine, 25 hp. Distribution system not specified. Fire hydrants, 21; no rental. Consumers, 112; all metered. Daily consumption, 40,000 gallons. Rate, 12½ cents per thousand gallons.

WATER ANALYSIS.

Laboratory No. 5702. Collected by H. A. Avery; analysis completed May 20, 1913.

Laboratory No. 6189. Collected by W. D. Starling; analysis completed October 30, 1913.

Bacterial Examination.	*5702*	*6189*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	....	50
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	....	5—
Chemical Analysis. Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	1.8
Nitrogen as free ammonia	.012	.012
Nitrogen as alb. ammonia	.032	.058
Nitrogen as nitrites	.003	trace
Nitrogen as nitrates	1	1.5
Total solids	412	405
Mineral Analysis.		
SiO_2	23	....
$Fe_2O_3+Al_2O_3$	3.4	....
Ca	82.6	....
Mg	19.8	....
Na+K	27	....
Cl	26	22
SO_4	49.4	43.77
HCO_3	315	227

Hardness group, 5; total solids group, 6.

WAMEGO.

Population in 1910, 1800. Water and light plant built in 1899 by the city. Water supplied from four wells 8 inches in diameter by 60 feet deep. Casing, Cook strainers and casing. Water pumped by two Worthington duplex steam pumps, 300 g. p. m. capacity each, against 180-foot head. Standpipe, 85 feet high, 65,000-gallons capacity, covered. Distribution system: 8-inch, 2000 feet; 6-inch, 900 feet; 4-inch, 5800 feet. Fire hydrants, 43. Consumers, 405; all metered. Average daily consumption, 92,000 gallons. Minimum rate, 75 cents per quarter. Rate per thousand gallons, 20 cents.

WATER ANALYSIS.

Laboratory No. 5271. Collected by D. A. Course; analysis completed October 7, 1912.

Laboratory No. 6040. Collected by D. A. Course; analysis completed September 13, 1913.

Bacterial Examination.	*5271*	*6040*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	40	5
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	3—	5—
in five .1 cc. tubes	3—	5—

Chemical Analysis.
Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	.8	0
Nitrogen as free ammonia	.006	.008
Nitrogen as alb. ammonia	.002	.004
Nitrogen as nitrites	.003	.001
Nitrogen as nitrates	6.00	1.2
Total solids	591	542

Mineral Analysis.

SiO_2	19.2	33
$Fe_2O_3+Al_2O_3$	6	2
Ca	112.6	100
Mg	17.7	13
Na+K	44	55
Cl	78.4	76
SO_4	116.5	97.9
HCO_3	264	261

Hardness group, 7; total solids group, 9.

WATERVILLE.

Population in 1910, 704. Plant built in 1912 by the city. Source of supply, one well 12 inches in diameter, 64 feet deep. Water pumped by double-action triplex 350 g. p. m., motor-driven pump, discharging to elevated tank, 78,000-gallons capacity. Fairbanks-Morse 80 hp. distillate oil engine is prime mover. Distribution system: 8-inch, 800 feet; 6-inch, 4500 feet; 4-inch, 10,200 feet; 2-inch, 1600 feet. Fire hydrants, 20; rental, $25 per year each. Consumers, 44; all metered. Daily consumption, 7000 gallons. Minimum rate, 50 cents per month, with sliding scale from 30 cents to 20 cents.

WATER ANALYSIS.

Laboratory No. 5884. Collected by G. Thacker; analysis completed August 4, 1913.

Laboratory No. 7061. Collected by city clerk; analysis completed October 10, 1914.

Bacterial Examination.	*5884*	*7061*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	3
Agar, at 37°—24 hrs.	200	15
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—

Chemical Analysis.
Results in parts per million.

Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	1	1
Nitrogen as free ammonia	.004	.044
Nitrogen as alb. ammonia	.014	.032
Nitrogen as nitrites	.0005	0
Nitrogen as nitrates	3.5	4
Total solids	521	532

Mineral Analysis.		
Cl	18	24
SO_4	33.3	13
HCO_3	464	464

Hardness group, 8; total solids group, 9.

WAVERLY.

Population in 1910, 750. Water and light plant built in 1907 by the city. Water supplies from two wells, one 10 feet in diameter by 20 feet deep and one 40 x 28 x 25 feet deep. Prime movers, one high speed automatic ball engine, 80 hp. and one Fairbanks-Morse 25 hp. oil engine. Water pumped by one compound duplex pump, 500 g. p. m., against 120-foot head. Standpipe, 80 feet high, capacity 30,000 gallons. Distribution system: 6-inch, 2500 feet; 4-inch, 2800 feet; 2-inch, 6000 feet. Fire hydrants, 13. Consumers, 65; all metered. Average daily consumption, 10,000 gallons. Minimum rate, 75 cents per month. Rate for 1000 gallons, 50 cents.

WATER ANALYSIS.

Laboratory No. 5242. Collected by F. W. Hubbard; analysis completed October 2, 1912.

Laboratory No. 5932. Collected by F. W. Hubbard; analysis completed August 14, 1913.

Bacterial Examination.	*5242*	*5932*
Bacteria per cc. on		
Gelatine, at 20° —48 hrs.	....	....
Agar, at 37° —24 hrs.	220	180
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	3+	5+
in five .1 cc. tubes	2+ 1—	2+ 3—
in five .01 cc. tubes	1+ 1—	....
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	0	.2
Nitrogen as free ammonia	.002	.002
Nitrogen as alb. ammonia	.014	0
Nitrogen as nitrites	0	0
Nitrogen as nitrates	2	.7
Total solids	692	646
Mineral Analysis.		
SiO_2	19.0	27.6
$Fe_2O_3+Al_2O_3$	5.2	2.6
Ca	132.5	86
Mg	37.5	26
Na+K	29	100
Cl	6	15
SO_4	237.5	211.9
HCO_3	357	364

Hardness group, 10; total solids group, 11.

WEIR CITY.

Population in 1910, 1770. Water is secured from two wells 6 inches in diameter 500 feet deep, cased with wrought iron to the Mississippi lime stone. Water is pumped into a 250,000-gallon reservoir on the surface and then pumped into a 70,000-gallon tank on a 100-foot tower. Distribution system: 8-inch, 1400 feet; 6-inch, 1800 feet; 4-inch, 20,000 feet cast-iron pipe.

WATER ANALYSIS.

Laboratory No. 5536. Collected by E. R. Sweeney; analysis completed January 21, 1913.

Laboratory No. 6007. Collected by Anderson; analysis completed September 5, 1913.

Bacterial Examination.	*5536*	*6007*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	50	150
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	4—	5—
in five .1 cc. tubes	....	5—
Chemical Analysis. Results in parts per million.		
Color	c	0
Turbidity	0	0
Oxygen consumed	.3	2.35
Nitrogen as free ammonia	.15	0
Nitrogen as alb. ammonia	.046	0
Nitrogen as nitrites	.001	0
Nitrogen as nitrates	0	0
Total solids	517	498
Mineral Analysis.		
SiO_2	7.6	14.2
$Fe_2O_3+Al_2O_3$	1.4	1.2
Ca	47.7	48
Mg	28.1	25.8
Na+K	105	94
Cl	66	73
SO_4	52.4	25.52
HCO_3	383.5	366.5

Hardness group, 4; total solids group, 8.

WELLINGTON.

Population in 1910, 7034. Combined water and light plant was built by the city. At present the source of supply is from a small reservoir on Slate creek. A new supply is being developed at the present time, consisting of eight wells, 24 inches in diameter and 60 feet deep, of the Layne & Bowler type, cased into 12 feet to 30 feet of sand and gravel. Water will be pumped by a Layne & Bowler type of submerged pump, with a capacity of 400,000 gallons per day each, into a large tank at Mayfield, from which it will flow by gravity into a tank and standpipe in the city of Wellington for delivery. Details of this plant have not yet been decided upon. However, there will be 40,000 feet of 18-inch steel pipe from Mayfield to the city of Wellington. The present steam plant

consists of a Worthington compound steam pump with a capacity of one million g. p. d. and a motor-driven turbine pump, with a capacity of 750,000 gallons per day. Distribution system: 12-inch, 1100 feet; 10-inch, 11,800 feet; 8-inch, 17,400 feet; 6-inch, 2186 feet; 4-inch, 4586 feet cast-iron pipe, and 2-inch 5000 feet. There are 105 fire hydrants, for which a rental of $36 per year each is paid. There are 1200 domestic and 98 business consumers, all metered. The daily consumption will average 1,250,000 gallons, a large part of which goes to the A. T. & S. F. Railroad. The minimum rate charged for water is $1 per quarter, with a rate from 15 cents down for large quantities.

WATER ANALYSIS.

Laboratory No. 6514. Source, new well; analysis completed March 16, 1914.

Chemical Analysis. Results in parts per million.	*6514*	
Turbidity	20	....
Nitrogen as free ammonia	.018	....
Nitrogen as alb. ammonia	.02	....
Nitrogen as nitrates	1.5	....
Total solids	137	....
Mineral Analysis.		
Cl	7.2	....
SO_4	31.7	....
HCO_3	68	....

WESTMORELAND.

Population in 1910, 484. Plant built by the city in 1913-'14. The source of supply, one well 25 feet in diameter and 38 feet deep into 4 feet of gravel. The well is excavated 6 feet into solid rock to provide additional storage below the layer of gravel. Prime movers consist of 2 Alamo, 15 hp. oil engines. Water is pumped by a 20-foot deep-well, triplex, 150 g. p. m. pump against a total head of 200 feet, into a 50,000-gallon covered tank on a 100-foot tower. Distribution system: 6-inch, 4785 feet; 4-inch, 8182 feet; 2-inch 1387 feet pipe. There are 23 fire hydrants.

WATER ANALYSIS.

Laboratory No. 6319. Source, new well; collected by W. Anthony; date of collection, December 30, 1913; analysis completed January 3, 1914.

Bacterial Examination.	*6319*	
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	750	....
Presumptive tests for *B. coli*	+	....
Number of positive fermentations:		
in one 10 cc. tube	+	....
in five 1 cc. tubes	3+ 2—	....
in five .1 cc. tubes	5—	....

Chemical Analysis.

Results in parts per million.

Color	none	....
Odor	none	....
Turbidity	none	....
Oxygen consumed	N. D.	....
Nitrogen as free ammonia	N. D.	....
Nitrogen as alb. ammonia	N. D.	....
Nitrogen as nitrites	none	....
Nitrogen as nitrates	none	....
Total solids	582	....
Mineral Analysis.		
Cl	12	....
SO_4	116.6	....
HCO_3	376	....

WEST MINERAL.

WATER ANALYSIS.

Laboratory No. 5745. Collected by L. T. Black; analysis completed August 28, 1913.

Laboratory No. 5746. Collected by L. T. Black; analysis completed August 28, 1913.

Bacterial Examination.	*5745*	*5746*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs.	....	....
Agar, at 37°—24 hrs.	2,500	670
Presumptive tests for *B. coli*	—	—
Number of positive fermentations:		
in one 10 cc. tube	—	—
in five 1 cc. tubes	5—	5—
in five .1 cc. tubes	5—	5—
in five .01 cc. tubes	3—	3—

Chemical Analysis.

Results in parts per million.

Color	milky	milky
Odor	H_2S	H_2S
Turbidity	40	20
Oxygen consumed	0	0
Nitrogen as free ammonia	.318	.088
Nitrogen as alb. ammonia	.03	.104
Nitrogen as nitrites	0	0
Nitrogen as nitrates	0	0
Total solids	1,023	1,005
Mineral Analysis.		
SiO_2	8	8.2
$Fe_2O_3+Al_2O_3$	.6	1
Ca	50.9	61.3
Mg	30.6	32.2
Na+K	290	273
Cl	351	344
SO_4	60.4	68.5
HCO_3	401	391

Hardness group, 5; total solids group, 18.

WICHITA.

Population in 1910, 52,450. Plant built in 1882 by private company. Present ownership, Wichita Water Company since 1887. Source of supply, forty-three 8-inch wells, depth 30 to 40 feet. Prime movers, six 60-inch by 16 feet Erie tubular boilers. Pumps: Prescott, five million gallons daily; Wood, four million gallons daily; Laidlaw, Dunn, Gordon, three and one-half million gallons daily; and Holly-Gaskill, five million gallons daily, direct pressure. Also, high-pressure system to Fairmount and College Hill district, served by one and one-half million gallons daily, Knowles pump, and three-fourths million gallons daily, Epping-Carpenter pump. Water siphoned from wells to one million gallon reservoir, from which high-service pumps take suction. Distribution system: 16-inch, 33,365 feet; 14-inch, 20 feet; 12-inch, 14,265 feet; 10-inch, 24,125 feet; 8-inch, 138,336 feet; 6-inch, 257,425 feet; 4-inch, 636 feet; 2-inch, 229,991 feet; total, 134.7 miles. Fire hydrants, 676; rental, $38.50 per year each. Consumers, 7600; 55 per cent metered. Average daily consumption, 3,-550,000 gallons. Minimum rate, 75 cents per month. Rate for 1000 gallons, 25 cents to 5 cents.

WATER ANALYSIS.

Laboratory No. 5094. Collected by city; analysis completed August 9, 1912.

Laboratory No. 5297. Collected by city; analysis completed October 18, 1912.

Laboratory No. 5010. Collected by Doctor Miller; analysis completed June 15, 1912.

Laboratory No. 5908. Collected by E. W. Leach; analysis completed August 6, 1913.

Bacterial Examination.	*5094*	*5297*	*5010*	*5908*
Bacteria per cc. on				
Gelatine, at 20°—48 hrs..	....	......	....	....
Agar, at 37°—24 hrs....	....	100	....	250
Presumptive tests for *B. coli*,	....	—	....	+
No. of positive fermentations:				
in one 10 cc. tube.......	....	—	....	+
in five 1 cc. tubes........	....	3—	....	1+ 4—
in five .1 cc. tubes.......	....	3—	....	5—
Chemical Analysis.				
Results in parts per million.				
Color	c	......	0	....
Odor	0	......	0	....
Turbidity	c	......	0	....
Oxygen consumed	0	......	.57	....
Nitrogen as free ammonia..	0	......	.016	....
Nitrogen as alb. ammonia ..	0	......	.056	....
Nitrogen as nitrites	.0075	......	0	....
Nitrogen as nitrates	0	......	0	....
Total solids	1255	......	1441	....
Mineral Analysis.				
SiO_2	14.4	......	10.2	....
$Fe_2O_3+Al_2O_3$	....	......	1	....
Ca	105	......	92	....
Mg	23.55	......	21.55	....
Na+K	326.3	......	290	....
Cl	459.6	......	283.2	....
SO_4	233	......	355.5	....
HCO_3	220.5	......	219	....

Hardness group, 7; total solids group, 26.

WILSON.

Population in 1910, 981. Combined water and light plant built by the city in 1910. Source of supply, two wells 10 feet in diameter and 20 feet deep, cased with brick. Power is furnished by a 110 and 50 hp. distillate oil engine, internal combustion type. Water is pumped by an 8-inch by 8-inch triplex pump into an elevated tank on a 100-foot covered tower. Distribution system consists of three miles of 8-inch; one mile of 6-inch; 3000 feet of 4-inch cast-iron pipe, and 1800 feet of 2-inch pipe. There are 32 fire hydrants. Daily consumption, 75,000 gallons. Minimum rate charged for water is 25 cents per month and 25 cents per thousand.

WATER ANALYSIS.

Laboratory No. 6118. Collected by N. B. Power; analysis completed October 15, 1913.

Laboratory No. 6880. Collected by city clerk; analysis completed August 11, 1914.

Bacterial Examination.	*6118*	*6880*
Bacteria per cc. on		
Gelatine, at 20°—48 hrs	....	....
Agar, at 37°—24 hrs	25	18
Presumptive tests for *B. coli*	+	+
Number of positive fermentations:		
in one 10 cc. tube	+	+
in five 1 cc. tubes	2+ 3—	3+ 2—
in five .1 cc. tubes	5—	3—
Chemical Analysis.		
Results in parts per million.		
Color	0	0
Odor	0	0
Turbidity	0	0
Oxygen consumed	3.05	1.7
Nitrogen as free ammonia	0	.01
Nitrogen as alb. ammonia	.34	.014
Nitrogen as nitrites	.02	.005
Nitrogen as nitrates	.1	20
Total solids	636	619
Mineral Analysis.		
SiO_2	23.4	22.8
$Fe_2O_3+Al_2O_3$	3.2	3.6
Ca	128	106.8
Mg	9	11.8
Na+K	15	68
Cl	62	104
SO_4	84.25	91.33
HCO_3	259	268.4

Hardness group, 6; total solids group, 10 .

BULLETIN OF THE UNIVERSITY OF KANSAS

VOL. XVI. MARCH 15, 1915. NO. 9.

ENGINEERING BULLETIN NO. 6.

KANSAS FUELS: COAL, OIL, GAS.

PART I.—HEATING VALUES AND PROXIMATE ANALYSIS OF COAL (Reprint)

BY

P. F. WALKER AND WALTER BOHNSTENGEL.

SUPPLEMENT BY H. R. BROWN AND C. B. CARPENTER.

PART II.—DISCUSSION OF SULPHUR CONTENT OF BITUMINOUS COAL (Reprint)

BY

WALTER BOHNSTENGEL.

PART III.—ECONOMIC EFFECTS OF WASHING COAL FROM THE STATE MINE

BY

C. M. YOUNG.

LAWRENCE, KANSAS.

Published Semimonthly from January to June and Monthly from July to December, inclusive, by the University of Kansas.

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6-624

THE Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of the Engineering Departments.

The Station designs to issue bulletins, of which this is the sixth number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The number of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

PREFACE.

The work represented in this bulletin has been under way for several years in the Mechanical Engineering Department laboratory. Several men besides the authors have had to do with it, notably Prof. Charles I. Corp, now of the University of Wisconsin, who collected many samples and did much to inaugurate the investigation on coal, and Mr. Albert F. Smethers, for a year laboratory assistant in the department and now engaged in practical engineering work, who prepared many laboratory samples and started the proximate analyses. Mr. Bohnstengel did most of the analytical and calorimetry work on coal, while in the position of laboratory assistant, that work having been completed and much of the final preparation of the report made since he became a member of the staff of the engineer of tests on the A., T. & S. F. Railway, in which position he has continued his fuel work and checked out many important points. The work on oil and gas has, in most part, been done by Professor Walker, aided by Prof. F. W. Bushong, of the Department of Industrial Chemistry Research of the University, in oil analyses, and by Prof. H. C. Allen, of the Department of General Chemistry, in gas analyses. The notable work of Professors Cady and McFarland of the Chemistry Department in their investigation of the constituents of natural gas has been drawn upon in some measure.

In matters relating to extent and stratigraphy of the fuel fields, and to production figures, material has been taken from the reports of the U. S. Geological Survey, credit for the same being given where used. For production figures in most recent years Prof. Erasmus Haworth, of the Kansas State Geological Survey, has kindly furnished information.

For all asistance thus rendered the authors desire to express appreciation and give full credit.

At different times, work in limited amount of the kind here presented has been done upon Kansas coal. Five samples were analyzed and tested in the laboratories of the U. S. Geological Survey, now of the Bureau of Mines, all of which sam-

ples, however, were taken from the large field in the southeastern part of the state. Volume III of the University Geological Survey of Kansas, published in 1898, dealing entirely with the coal and coal fields, contains records of work done on about forty samples. These samples were taken in a different manner from those taken in the present investigation, and the calorimetry work was not done with apparatus of fully recognized accuracy. Valuable as these records are, they are not in form for as convenient reference as when published separately, and it was necessary to collect a complete new set of samples for the aditional and corroborative work. It seemed best, therefore, to omit the former analyses and proceed with the present set of samples independently. It is believed that the results herein published are reliable, and representative of the coal actually on the market from the mines of the state.

PREFACE TO SECOND EDITION.

The issue of the bulletin in its original form, Engineering Bulletin No. 3, was quickly exhausted and frequent requests for copies led to the decision to reprint the material with such additions as should be available. The new matter appears (*a*) in the form of a supplement to the work on the coals of the state, prepared by two senior mining engineering students, Messrs. H. R. Brown and C. B. Carpenter; (*b*) as Part III, "Effects of Washing Coal," by Prof. C. M. Young, until lately at the head of the technical mining work of the University and at present editor of *The Colliery Engineer*. The additions are of such valuable nature that a new number has been given to the bulletin in the Station series.

MARCH, 1915.

UNIVERSITY OF KANSAS.

ENGINEERING EXPERIMENT STATION.

BULLETIN NO. 6. MARCH, 1915.

KANSAS FUELS: COAL, OIL, GAS.

CONTENTS.

Part I. Heating Values and Proximate Analysis of Coal.

(Reprint.)

BY

P. F. WALKER, Professor of Mechanical Engineering.

WALTER BOHNSTENGEL, formerly Assistant in Fuel Laboratories.

SUPPLY.

The fuels of Kansas include coal, petroleum, and natural gas.

The coal-mining industry has been an important one for the past forty years, and at present furnishes employment for about 13,000 men. The amount mined in this period is 2.2 per cent of the total known deposit, and at the average rate of the past five years it will take 762 years to exhaust the supply. The price of the coal has risen gradually, and it is probable that under the stimulus of the various enterprises established in southeastern Kansas during the prevalence of cheap gas during the past ten years, the demand for coal will increase and this industry will experience a growth greater than in the immediately preceding years.

Petroleum products became a factor of importance in the last decade of the nineteenth century, but had its most important development in 1903-1904. Since the latter date the tendency to drop in production is evident, but the past two years show a slight increase over 1910, due to advance in the price paid for crude oil. The prices obtainable in the midcontinental field have been uniformly low in proportion to the value of the stock, and this has kept production down below normal figures.

Natural gas has been produced in the state for more than twenty years, and became an important factor in the years 1902 to 1905. Production continued to increase until 1909, but is now declining rapidily.

Among the states the normal position of Kansas as a coal producer is in tenth place, although in 1910 the production fell to an abnormally low figure because of strikes among the miners. As an oil producer its position was ninth in 1910, and it is likely to pass into eighth place in the near future. As a

gas producer it was third in 1909, but has since declined, and figures to determine its exact status are not available.

Table of Fuel Products: Production and Value.

Year.	Coal.		Oil.		Gas.	
	Tons.	Value.	Barrels.	Value.	Cubic feet.	Value.
1908	6,245,507	$9,292,222	1,801,781	$746,695	80,740,264,000	$7,691,587
1909	6,986,478	10,083,384	1,263,764	491,633	75,074,416,000	8,293,846
1910	4,921,451	$7,914,709	1,128,668	$444,763	*	
1911	6,254,228	9,654,572	1,227,932	626,431	*	
1912	6,350,396					
1913	7,090,579					

*Not determined for Kansas alone.

EXTENT OF COAL FIELDS.

The following statement is taken from the U. S. Geological Survey Report on the Mineral Resources of the United States for 1910:

"The coal measures of Kansas occupy the eastern portion of that state and underlie approximately 20,000 square miles, of which 15,000 have been estimated as probably more or less productive. The coal measures belong to the Pennsylvania series of the Carboniferous, and include the southwestern extension of the Iowa-Missouri field. The deposits differ somewhat from those of the adjacent states, in that the division between the upper and lower portions is not so well marked. The limestones, which in Iowa and Missouri characterize especially the upper portion of the coal measures, are more prominent in Kansas, and coal is also found to some extent in the upper beds as well as in the lower. The total thickness of the coal measures has been estimated at 3000 feet. The dip is to the north and west, and the beds increase in thickness in that direction. The most important coal field in the State is that of Cherokee and Crawford counties, in the southeastern corner. In this field the Cherokee bed, which varies in thickness from 3 to 10 feet and has a general average of 40 to 42 inches, is largely mined. The coal is of better grade than found in adjacent states, and the mining conditions as regards roof and floor are excellent. Approximately 91 per cent of the output of the State comes from these counties. Some of the coal mined in this district possesses coking qualities, and a small quantity of coke is made from slack coal produced at the mines in the vicinity of Pittsburg. About half of the coal used in coke making is washed before being charged into the ovens. The coke is used by the zinc smelters in and about Pittsburg.

"Some of the coal beds lie very near the surface, and mining operations are carred on by removing the overburden and stripping the coal. Some of this strip-pit coal is used raw in the smelting of zinc, for

which purposes its absolute noncoking qualities make it especially adaptable. This fuel is known locally as 'dead coal.'

"The second district of importance is that adjacent to Leavenworth and Atchison, in the northeastern portion of the State, where, at a depth of from 700 to 1150 feet and at horizons equivalent to those mined in eastern Missouri, a thin bed of coal is found. This field yields a trifle less than 6 per cent of the total output of the state and is notable as being the only point at which deep mining is carried on in the western interior coal field. The third important district in Kansas is that of Osage and adjacent counties, in which a coal bed 20 to 22 inches thick is mined and yields approximately 3 per cent of the state's output. This bed is notable as being well up in the upper coal measures and stratigraphically 2000 feet above the Cherokee coal. It occupies approximately the horizon of the bed locally mined in southwestern Iowa.

"According to the estimates of M. R. Campbell, the total area of Kansas known to contain workable coal beds is 3100 square miles, while the area of which little is known, but which may contain workable coal, is estimated at 15,780 square miles."

The coal fields are crossed and to a large extent developed by the Atchison, Topeka and Santa Fe; Kansas City, Mexico & Orient; Kansas City Southern; Leavenworth, Kansas & Western; Missouri, Kansas & Texas; Missouri Pacific; St. Louis & San Francisco, and Union Pacific railroads.

EXTENT OF OIL FIELDS.

The Kansas oil field is a portion of the so-called midcontinental field, which covers portions of Kansas, Oklahoma and northern Texas. The productive portion lies chiefly in ten counties in the southern and eastern portion of the state, forming a belt extending from northeast to southwest, just west of the principal coal deposits. As fuel for general purposes, outside of gasoline products, it is not of especial importance under present commercial conditions, and is not considered at great length in this bulletin.

EXTENT OF GAS FIELD.

The gas field coincides generally with the oil field, although of slightly greater extent. The product has been of great importance in the development of manufacturing interests of several kinds in the southeastern part of the state, especially in cement, glass and brick plants and in smelters. The supply is becoming exhausted rapidly, however, and it will not long continue as a factor of commercial importance excepting in localized districts.

NATURE OF FUEL IN GENERAL.

The particular elements entering into the composition of fuels are carbon and hydrogen. Several other elements are usually present in small quantities, such as nitrogen and oxygen, which are volatilized in combustion, while other solids—noncombustible substances known as ash—are always present in varying quantities. Sulphur is present in many cases, in quantity as high as 6 or 7 per cent by weight in some coal on the market. It has a heat value of 4050 heat units per pound when burned in a dry atmosphere, but it is so objectionable from many viewpoints as a fuel constituent that its presence is undesirable. Government contracts for coal usually specify an upper permissible limit of 5 per cent sulphur for general purposes at land stations. For stoking purposes in the navy much smaller sulphur content is allowed.

Both carbon and hydrogen unite chemically with oxygen with great rapidity when heated, and generate heat in the process. This is known as the process of combustion. Two and one-third pounds of oxygen, or 11.3 pounds of air, are required per pound of carbon for this process, and the heat produced is 14,600 heat units. That is, it would heat 14,600 pounds of pure water one degree Fahrenheit, at or near 60 degrees. With an insufficient supply of oxygen, carbon monoxide gas is formed, producing 4450 heat units. Hydrogen burns to water gas, H_2O, requiring 34.56 pounds of air per pound, and producing 62,000 heat units. This high heat value makes of hydrogen a valuable constituent in fuels. Oxygen in a combined state is often associated with the hydrogen, however, and serves to cut down its available heating value in corresponding proportion. It is universally true that those coals running high in hydrogen content also contain oxygen, so that the presence of large quantities of the volatile gaseous constituents means that after passing a certain limit the increase in heat value due to hydrogen ceases. The exact proportion of volatile gases in the coal which gives the particular combination for a maximum heat value is not a fixed quantity, but is generally in the neighborhood of 18 per cent.

When coal is heated gradually a certain part of it will pass off as a volatile gas before the actual chemical process of combustion begins. These volatile gases include the hydrogen, oxygen and nitrogen, together with hydrocarbon gases, in the

forms of marsh gas, olefiant gas, volatilized pitch, etc. The term "volatile matter" is commonly employed to indicate this material. In the furnace the volatile portion burns above the bed of fuel, and in the manufacture of artificial gas it passes without burning directly into the product. The solid fuel remaining is composed of what is termed "fixed carbon," and any solid noncombustible matter which forms a residue or ash. This solid fuel is the coke of commerce, the best qualities of which are made from coal containing small amounts of ash and sulphur.

Petroleum, in its various forms, is a compound of carbon and hydrogen in various proportions, with some oxygen, and is very complex in chemical character. The leading group of hydrogen compounds present in the Kansas petroleum is the paraffine series, having the chemical equation C_nH_{2n+2}. Traces of sulphur may be present, but commonly there is not enough of this element to be especially objectionable. The average proportions of the main elements, as determined by ultimate chemical analysis of a typical sample of Kansas oil, are:

Carbon	85.43 per cent.
Hydrogen	13.07 per cent.
Oxygen	1.00 per cent.
Nitrogen	0.13 per cent.
Sulphur	0.37 per cent.

The natural gas of Kansas and Oklahoma is composed mainly of the hydrocarbon compounds knows as methane and ethane for which the chemical formulæ are CH_4 and C_2H_6. There is always present nitrogen to the extent of 2 to 5 per cent, and small quantities of several other gases. Complete chemical analysis reveals the presence of several hydrocarbon gases other than CH_4 and C_2H_6, but their amounts are small and their properties are so nearly the same that no appreciable error is involved in the usual assumption that the entire combustible portion is composed of these two hydrocarbons. The following table of analyses is taken from Engineering Bulletin No. 2 of the present series:

Table of Gas Analyses Made at the University.

DATE.	CH_4. and C_2H_6.	Other hydro-carbons.	CO.	Total com-bustible.	CO_2.	Oxygen.	Nitrogen.
May 16, 1906	98.06	0.0	0.00	98.06	0.20	0.0	1.74
Dec. 23, 1907	94.47	Not taken.	0.00	94.47	1.85	Trace.	3.68
Jan. 11, 1910	95.20	Not taken.	0.00	95.20	0.80	0.2	3.80
Feb. 1, 1910.	93.80	Not taken.	0.00	93.80	0.60	0.2	5.40
Mar. 4, 1912	91.10	2.4	0.45	93.95	0.40	0.6	5.05

CLASSIFICATION OF COAL.

Coal is classified according to the proportions of volatile gas and fixed carbon contained in the combustible portion. Due to varying causes, the process of distillation of water and volatile substances of the original vegetable fiber during its transformation into the coal has gone on at varying rates in different sections of the country. The combustible portion is that remaining after the weights of moisture and noncombustible ash have been deducted, so that the two items of volatile gases and of fixed carbon may be expressed as percentages of this combustible portion, together forming 100 per cent.

The standard classification in the United States is as follows:

ANTHRACITE: When volatile matter is not more than 7½ per cent of the total combustible.

SEMI-ANTHRACITE: When volatile matter is from 7½ to 12½ per cent of the total combustible.

SEMI-BITUMINOUS: When volatile matter is from 12½ to 25 per cent of the total combustible.

BITUMINOUS: When volatile matter is from 25 to 50 per cent of the total combustible.

LIGNITE: When volatile matter is over 50 per cent of the total combustible.

In physical characteristics, coal from one section of the country may differ considerably from coal which by analysis belongs to the same class but which was mined in another section. A certain general tendency is very noticeable in the distribution of coal over the United States, in that there is a nearly regular gradation from anthracite down the list in passing from the extensive eastern Pennsylvania coal fields westward. Exceptions to that occur in the anthracite coal of Colorado and the semi-anthracite of Arkansas, but the tendency is clearly evident. In the Mississippi valley bituminous coals only are found, with the exception noted above, and with some lignitic coal in the northern regions of Iowa and Montana. In the Missouri deposits, of which the Kansas coal fields form a part, the coal is in the bituminous class, but usually with comparatively large percentages of volatile gases.

METHODS OF INVESTIGATION.

In the main, the methods followed in the analytical work on coal in the laboratory were those used and recommended by the chemists of the U. S. Geological Survey and Bureau of Mines and by the American Chemical Society. In some instances the practice was varied in unimportant details in order to suit local conditions, but extreme care was taken to preserve the full degree of accuracy.

SAMPLING.

It is recognized that in all work with coal the value of results is directly dependent upon the accuracy with which the sample represents the material being judged by the investigation. It was decided to base the present work on coal actually being delivered to consumers by rail, under the normal conditions of mining. It will be apparent that this differs in some respects from the method of investigating the vein of coal. Investigations of the latter sort express more accurately, it is true, the exact quality of the coal and represent more truly the possibilities of the mine. In the present study, however, the purpose has not been so much a study of the characteristics of coal as it has been a study of the coal available to consumers in the open market. This is the problem met with by the user of fuel, which was the true purpose in view when the work was undertaken. The question of efficiency of mining is involved here, since the elimination of the material from the underlying and overlying strata will bear directly upon the results obtained in analysis. The man who is purchasing coal is not so much concerned with what the mine contains in the form of pure fuel as he is with that fuel which he receives regularly.

In following out this plan all samples were taken at the surface. This was usually done by taking the coal as it was being dumped from the hoisting cars in the tipple over the screens to cars in the process of loading. From each car hoisted in the mine a small shovelful of coal was taken at random, lumps large and small, and fine slack, all being mixed together for the mine-run samples. As the mining process is carried on, each shift of cars drawn to the base of the shaft at the working levels is made up of cars from the various sections of the mine, only one or two coming from a single room. It was known,

therefore, that a composite sample taken from a given number of cars represented somewhat more than one-half as many rooms, and by waiting over the short intervals of time following the hoisting of the cars from one shift, and then continuing sampling from cars coming in from a second shift, another set of rooms in an entirely different quarter of the mine would be represented. This was the practice regularly followed, and in many cases practically every portion of the mine would be represented in the sample taken. This sample, amounting in weight to several hundred pounds in most cases, was then quickly broken down to approximately uniform size and quartered down by the familiar method of dividing the heap of crushed coal into quarters, after thorough mixing, and eliminating the opposite portions, this process of elimination being continued until the sample was down to the capacity of a quart fruit jar, which was then sealed tightly and taken to the laboratory. In a very few instances samples were taken from railroad cars which had been loaded, but in these cases care was taken to work carefully over the car, to dig to different levels, so as to secure a representative body of coal. In every instance where this method was followed it was in a region where samples had been taken by the standard method from mines in the same locality. In several instances, when the standard sample had given a result by analysis different from that which had been expected in the locality, duplicate samples from the same mine were secured at later dates. In most cases where this was done the results of the second analysis substantially corroborated the work on the first sample.

Recognizing the great importance of the sampling of coal, a special effort was made at one mine to determine accurately the differences among samples taken at varying points and in different manners. To this end, with the aid of several qualified assistants, samples were taken underground by cutting through the vein of coal at the working face, after carefully clearing away the strata above and below, at four different points where the work was progressing regularly in the mine. In each case a V-shaped notch about 6 inches deep was cut through the full depth of the vein and the coal removed carefully and quartered down in the usual manner. At the same time that this was being done, samples were being taken at the surface in the standard manner, with the difference that sep-

arate samples were taken from the several grades into which the coal was being screened. These grades were four in number, the first being large lumps passing over the 5½-inch screen, making up 43 per cent of the total coal; the second, "railroad lump," passing through the 5½-inch screen and over the 3½-inch, making up 26 per cent of the coal; the third, egg coal, passing through the 3½-inch screen and over the 2-inch screen, making up 9 per cent of the coal; and the fourth, mixed nut and slack, passing through the 2-inch screen, making up 22 per cent of the coal. By this means a study of the composition of the various grades was possible, showing the manner in which the coal naturally broke, as well as making it possible to use the composite sample in comparison with the several samples taken at the working face of the vein, underground. The results of this appear in the table on page 14.

From the data given above, it will be noted that in the samples taken above ground an increased amount of ash is present, which is a result to be expected. Moisture in the underground samples is greater, the samples being subjected to less air-drying, and it is possible that some other than hygroscopic moisture was present. On the whole, however, comparing the composite sample taken above ground with the average of the four samples cut from the working face of the vein, a remarkable similarity exists. When reduced to the terms of combustible, the percentages are found for volatile gases and fixed carbon respectively to be practically identical. The efficiency of the mining process is also shown by these figures.

As to the varying nature of the coal, based on the gradation according to size of lumps, no very consistent laws are noticeable. There is a tendency for the fixed carbon to become less in the smaller grades and a very noticeable increase in the ash occurs in the slack. Evidently the sulphur-bearing seams, present to excess in a portion of the vein, are so spaced as to cause the breaking of the coal into medium-size lumps, the sulphur adhering to these lumps and appearing in greater percentage in the samples. It is clear that the sulphur is not in excess in the noncombustible portions, since the high ash content of the slack is accompanied by a comparatively small amount of sulphur. The mine thus sampled is in the Leavenworth district, and there is no evidence to show that similar

Proximate Analyses of Special Samples from a Single Mine.

Sample No.	Origin and Grade of Coal Sample.	Sample as taken.				Dried sample.			Combustible.		Sulphur.		Per cent of output.
		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Volatile matter.	Fixed carbon.	Ash.	Volatile matter.	Fixed carobn.	Sample as taken.	Dried sample.	
	Surface Samples:												
55	Fancy lump, over $5\frac{1}{2}$ in. screen	8.05	32.15	48.40	11.40	34.90	52.65	12.45	39.85	60.15	4.15	4.51	43
56	Railroad lump, over $3\frac{1}{2}$ in., through $5\frac{1}{2}$ in. screen	7.70	31.45	49.55	11.30	34.05	53.65	12.30	38.85	61.15	4.85	5.25	26
59	Egg coal, over $1\frac{1}{4}$ in., through $3\frac{1}{2}$ in. screen	7.00	30.75	49.20	13.05	33.05	52.90	14.05	38.40	61.60	4.76	5.12	9
65	Nut and slack, through $1\frac{1}{4}$ in. screen	8.25	29.00	42.40	20.55	31.60	46.00	22.40	40.75	59.25	4.50	4.90	22
	Composite analysis for run of mine	7.90	31.14	47.45	13.51	33.79	51.47	14.74	39.66	60.34	4.46	4.84	100
	Mine Samples:												
57	Room 9, northeast side, 20 in. vein	8.65	32.35	50.20	8.80	35.40	54.95	9.65	39.20	60.80	3.97	4.35	......
60	Room 1, southwest, 20 in. vein	8.15	31.70	49.85	10.30	34.55	54.25	11.20	38.90	61.10	4.30	4.68	......
61	Room 2, northeast side, 20 in. vein	9.00	32.20	47.80	11.00	35.35	52.60	12.05	40.25	59.75	4.78	5.25	......
62	Room 1, northwest, 21 in. vein	9.10	31.55	47.75	11.60	34.75	52.50	12.75	32.80	60.20	4.79	5.27	......
	Average of mine samples	8.75	31.95	48.90	10.40	35.02	53.56	11.42	39.54	60.46	4.46	4.89	......

conditions exist in other regions. The purpose of this special brief investigation was to demonstrate the accuracy of the sampling method employed.

Samples were taken from the three important coal districts in the state, which districts have been described in the section above headed "Extent of Coal Fields." In the largest district, mainly in Crawford and Cherokee counties, thirty-four mines were sampled. In the Leavenworth, Kan., region, where the coal is all taken from a small number of comparatively large mines, four samples were taken, one of these being the state mine, represented by several separate analyses made on coal used regularly in the State University plant. In the Osage county district sixteen mines were sampled, this number being comparatively large in proportion to the amount of coal mined.

The accompanying map, following page 50, shows the location of these mines, the number given corresponding to the number of the sample occurring in the tabulated list of the results.

PREPARATION OF SAMPLE.

The entire sample, consisting of the contents of a full quart fruit jar, was brought sealed to the laboratory and there crushed in an iron crusher of the coffee-mill type, down to a size passing a 10-mesh sieve. After thorough mixing, this was quartered down by the usual method until about two ounces remained. This reduced sample then became the laboratory sample on which all subsequent work was done.

Considerable attention was given to the further preparation of this small sample. When ground to a fineness sufficient to pass a 100-mesh sieve, so much time is usually required that air-drying is likely to cause a considerable reduction in the moisture content. The first grinding and general handling of the sample is sufficient to remove all surface or mine moisture, so that in this final grinding it seems clear that there is an actual loss of hygroscopic moisture. A quicker grinding of the two-ounce sample in a pulverizer, however, brings it to a condition where a considerable portion will pass the 100-mesh sieve, and all would pass a 60-mesh sieve. With samples prepared in these two ways, several comparative moisture determinations were made, and it was decided that, on the whole, the quickly ground but unsieved coal gave results more

reliable in the item of moisture, and fully as accurate in all other determinations, including the combustion for heat value in the calorimeter. The latter method was therefore adopted as the standard method throughout the course of the investigation.

PROXIMATE ANALYSIS.

Moisture Determination.

Exactly one gram of coal in each instance was weighed into a crucible on a standard analytical balance, and then placed in the usual form of drying oven heated by gas flame to a temperature of about 220 degrees Fahrenheit. One hour was the time regularly allowed for the drying process, although some experimenting was done here to determine whether a longer or shorter time would give better results. It was found, however, that one hour gave substantially the same results as longer periods, so that no change was made from the usually recognized practice. Other experiments with different temperatures led the authors to the opinion that a variation of 10 to 20 degrees above 220 is not sufficient to cause any loss of volatile gases; but, on the other hand, there is nothing gained in using these higher temperatures. The time of one hour seems to be approximately the time required to drive from the particles of coal all hygroscopic moisture, and with the higher temperatures mentioned there is increasing danger of slight oxidation of carbon at the surface of the mass in the crucible.

Volatile Matter.

In determining volatile matter the method followed was to take the sample just dried and weighed to determine moisture, with a close-fitting cover over the crucible, and place it over a Bunsen flame for seven minutes. The gas used was the natural gas from the midcontinental field, and best results were found by placing the crucible from six to eight centimeters above the top of the burner. When burning free this gas would burn with a flame about twenty centimeters high.

During the first few minutes of this process, beginning as soon as the coal became heated to a dull red, the gases passing off burned with a smoky flame upon issuing from the covered crucible. Toward the end of the period this burning ceased, at which time the crucible and coal within would be at a brilliant red heat. Experimenting at this point to determine

whether all of the gases were driven off at the time when flaming ceased, indicated that this would not be true in all cases, and the more appropriate method proved to be that of giving the sample the full period of seven minutes for the driving off of all volatile gaseous matter. It seems evident that different grades of coal require different methods of treatment in this respect, some yielding consistent results when the distillation is stopped when the flame disappears, while other coals, particularly those higher in volatile matter, continue to distill gases after burning ceases. Undoubtedly this is due to the larger nitrogen content of these volatile coals.

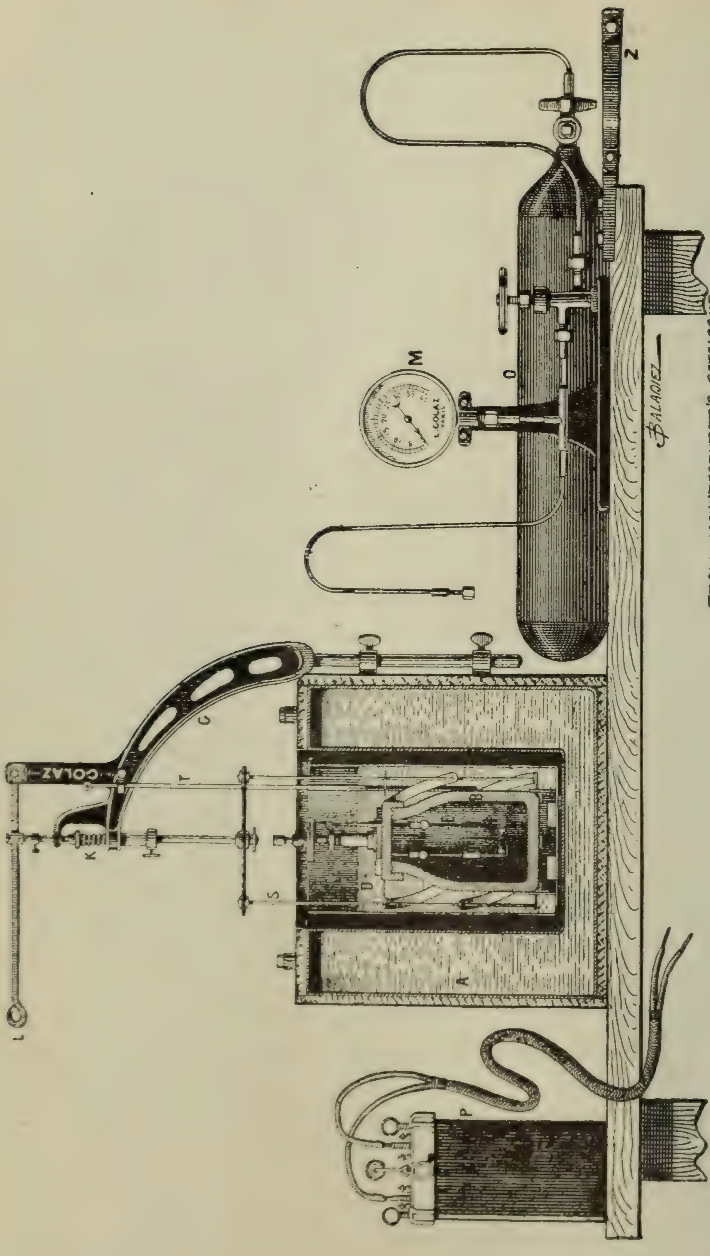
Fixed Carbon.

In determining the fixed carbon it is necessary to burn either the same sample used for the above determinations, or a newly weighed one-gram sample of green coal, entirely to the ash residue. Practice differs between these two methods, due mainly to existing conditions controlling the rapidity of the process. In the present investigation both methods were used, but for the larger portion of the samples the remaining quantity of coke, after the completion of the distillation of the volatile matter, was brought back to the blast burner and the carbon burned off directly in the open crucible. In order to facilitate this process a special brick oven was constructed, confining the heat in a high degree, so that several samples could be burned simultaneously under conditions of extremely high temperature. Since much of the coal is of the noncoking variety, this method was generally as expeditious as is the method of burning the green coal sample directly. Usually half an hour was sufficient to burn the sample to constant weight.

In this final weighing, as was also true in the weighing for moisture and volatile matter, the crucible was cooled to normal temperature in desiccators, employing calcium chloride for the absorption of atmospheric moisture. The differences obtained between these weighings give the four desired quantities. When running samples in large numbers this method of procedure is found to keep the operator employed continuously and is as expeditious as any method possible.

HEATING VALUES.

The heating values of all solid and liquid fuels have been determined by direct combustion in the Mahler bomb calorimeter of standard design, constructed by L. Golaz, in Paris, France. The oxygen used in the combustion was secured from



FROM MANUFACTURER'S CATALOGUE.

FIG. 1. Section of calorimeter.

the Linde Air Products Company, of Buffalo, N. Y. It is purchased in tanks under heavy pressure, so that it may be run into the calorimeter bomb directly, facilitating the work of the process in great measure.

Description of Apparatus.

In brief description as to construction and use, the instrument consists of the following parts:

A heavy steel bomb, porcelain lined, of about 550 cubic centimeters capacity, fitted with screwed cap. This cap terminates above in a central standard about 10 centimeters high, hollow, fitted with a needle valve operated by a milled handpiece, and through which the oxygen is admitted and the generated gases of combustion discharged. Inside the cap are attached two platinum wires extending about half way to the bottom of the bomb, one having metallic contact and the other passing through an insulated opening for electrical connection above. One of these wires supports the platinum tray in which the fuel, carefully weighed, is placed, and across the lower ends of the two is passed a piece of fine iron fuse wire of determined weight, so looped as to touch the fuel. This wire should be such that a current of two amperes will fuse it quickly, its function being to ignite the fuel. In the presence of the compressed oxygen, a pressure of from 18 to 25 atmospheres being employed, combustion of both wire and fuel is extremely rapid, and, in order to withstand the exceeding high pressure produced, the bomb and all its connected parts must be constructed with wide safety margins and handled with great care. The cap screws down to a lead gasket set in a groove to prevent blowing out, the surfaces of which must be carefully watched and protected from scratches. The needle valve is comparatively soft, to seat itself under reasonable pressure applied on the screw, and must be kept in good condition by occasional dressing with a round, fine file. The cap is likely to stick in the heavy threads and be difficult of removal after a combustion, and to remedy this condition ordinary vaseline may be used sparingly as a lubricant. Care must be exercised to keep all lubricant outside the lead gasket, and to leave uncontaminated the rinsings of the bomb used for sulphur determination.

A copper cylindrical pail or bucket, large enough to contain the assembled bomb, together with 2200 to 2400 cubic centi-

meters of distilled water and affording space around the bomb for the copper agitator. The water must entirely cover the bomb and cap proper, leaving projecting above the surface the insulated platinum wire and the central standard which is used as the other pole.

An insulated covering, consisting of a double-walled cylindrical vessel containing in the annular space water at proper temperature. The inner diameter of the cylinder is sufficient to receive freely the copper water bucket, and the height is somewhat greater than the depth of water in the bucket. This latter precaution serves to maintain a condition of uniform temperature immediately above the exposed water surface, unaffected by sudden variations in the room, and places the entire mass of water employed as a heat absorbent more directly under the controlling influence of the water-jacketed insulator. The water bucket is supported on a wood triangle in the bottom of the cylindrical compartment, so that it is surrounded entirely by an atmosphere of air in close contact with the insulating covering.

Supported in bearings on the side of the outer cylinder is a curved standard, supporting the stirring mechanism over the center of bomb and cylinder and the thermometer suspended in the water close beside the bomb.

The thermometer is divided in fiftieths of a degree centigrade, can be read directly to hundredths, and, by magnifying glass, the operator can estimate thousandths of a degree. It is certified by the standard standardizing inspectors at Paris.

Other parts, for handling and operating, consist of pressure gauge and operating valves for the oxygen connection, clamping vise for the bomb, wrenches, etc.

Principles of Operation.

In preparing a sample of coal for combustion, some authorities hold to the method of compressing the finely ground particles into briquettes. The main purpose of this is to prevent loss of dust particles after weighing, and scattering inside the bomb under the impact produced at the ignition, which may occur very suddenly. Comparative investigations along this line have failed in revealing any such effects, and the authors have become satisfied that the weighing into the platinum tray of the powdered particles is a method reliable within all possible limits of observations. This method has, accordingly, been followed throughout the work with coal.

In operation, certain general principles must be understood. In the atmosphere of oxygen in the bomb, provided a sufficient amount is present, the fuel burns completely. That is, carbon burns directly to CO_2 and hydrogen to H_2O with full liberation of heat. The heat is utilized in raising the temperature of the water in the copper bucket immediately surrounding the bomb, and the temperature of the bomb itself and all other parts of the apparatus directly in contact with the water. The influence of this mass at increased temperature upon the surrounding atmosphere and other bodies, or, we may say, the counter influence of those surrounding substances on the masses being directly heated, is small, and is accounted for by methods for correcting the observed rise in temperature of the water. These methods are discussed at some length in the following pages.

It is clear that in order to make effective the full amount of heat liberated in the chemical process of combustion, the gaseous products must be cooled down to the initial temperature. Since the preparation of the material is best carried out at room temperature, this means cooling back to a like temperature, which is accomplished substantially by making the quantity of heat-absorbing material, mostly water, large in proportion to the amount of heat generated. As the process is regularly carried out, the increase in temperature is but from 2.0 degrees to about 4.0 degrees Centigrade for fuels ranging from coal of 10,000 heat units to oil of 20,000. Since the gases confined in the bomb pass through temperature ranges of several thousand degrees, this small variation amounts to but a small fraction of one per cent, which is well within the limits of error in observation.

With fuels containing hydrogen another element enters here, in that the recooling of the gases condenses the superheated water vapor to liquid form. At the same time, moisture in the coal, hygroscopic or otherwise, is first evaporated and then condensed. The latent heat released by this condensation from hydrogen combustion is thus registered as a part of the heat value of the fuel, although it is not effective in raising the temperature of the gaseous products of combustion. For this reason, in many cases where products of combustion are used at temperatures never falling to the condensing point, it is customary to deduct the value of this latent heat from the

quantity determined by the calorimeter method, and to call the difference the "available" heating value. There is an inconsistency in making this single correction, since in the actual case the heat represented by the difference in temperature of the gaseous products when finally discharged and of the fuel and air when mixed in the furnace is also not "available." The latent heat is by far the largest item, however, and practice sanctions the method. An attendant result of this condensation of water vapor, both from hydrogen combustion and inherent moisture, is the presence of moisture in the bomb and resultant chemical activity, in a manner discussed in the following paragraphs.

Inside the bomb, before the cap is screwed down, is nitrogen of the air. As a part of the volatile gases of the fuel there may be a small additional amount of nitrogen. This amount of nitrogen, with water and excess of oxygen, forms nitric acid in accordance with the equation

$$2H_2O + 2N_2 + 5O_2 = 4HNO_3$$

This reaction is accompanied by the generation of heat, and since it can not occur during combustion in the usual dry furnace atmosphere, a correction must be made by subtracting the amount of the heat formed. The amount to deduct is determined by titrating the bomb rinsings with a standard alkali solution of sodium carbonate, Na_2CO_3. For convenience in operation, the strength of the solution is made such that each cubic centimeter of the solution required to overcome the acidity of the rinsings shall represent one calorie, the metric unit of heat being used, since all observations are made on that basis. To accomplish this, since the heat of formation of nitric acid is 227 calories per gram, each c.c. of the solution must contain enough sodium carbonate to offset $\frac{1}{227}$, or 0.0044 grams of the acid. By the laws for neutralization of acids, it follows that the amount of sodium carbonate necessary is 3.706 grams per liter, thus fixing the strength of the standard solution.

The second chemical change brought about by the presence of moisture in the bomb is the burning of the sulphur of the fuel to sulphuric acid instead of to sulphur dioxide. The latter combustion is the one which normally takes place in the dry furnace, and in it heat is generated at the rate of 2250 calories per gram of sulphur. When burned to acid, however, 2230 ad-

ditional calories are generated per gram of sulphur while the titration requires more of the sodium carbonate solution to neutralize all acid in the rinsings, and each c.c. is counted as one calorie out, on the basis of all acid present being nitric. Each c.c. of the alkaline solution is equivalent to 0.00108 gram of sulphur in sulphuric acid, or to $0.00108 \times 2230 = 2.41$ calories of this excess heat. One calorie has been deducted on the basis of nitric acid, leaving 1.41 calories more to be deducted for each c.c. of the sodium carbonate solution. This means a correction of $^{1.41}/_{0.00108} = 1306$ calories per gram of sulphur, or 13.06 calories for each per cent of sulphur in the fuel. When the percentage of sulphur has been determined, all that remains is to multiply the result by 13.06 and deduct the value so found from the apparent heat value in calories, after the so-called sodium carbonate titration figure has been similarly deducted. In a succeeding chapter of this bulletin the probable relative values of sulphur percentage and the amount of standard sodium carbonate solution used in titration will be discussed, from which it will be seen that an estimate of sulphur may be made from the titration result, sufficiently accurate for the heat-value correction in commercial work, the probable error becoming not more than one-tenth of one per cent.

One important matter underlying accurate calorimetry work consists in the proper regulation of temperatures of water in the jacket and around the bomb of the instrument, and the finding of the proper corrections to be applied to the observed rise in temperature of water during combustion. Since this corrected temperature rise is to be multiplied by the weight of water around the bomb plus water equivalent of the calorimeter parts, a total quantity of 2700 grams according to the method followed in the present instance, it follows that an error in temperature readings and corrections will be multiplied by 2700. The need for care is obvious. The corrections often amount to 20 or more thousandths, representing 60 or more calories, or over 100 B. t. u.

Under usual conditions the water used around the bomb is at a lower temperature than the atmosphere in immediate contact with it and its containing copper bucket, this atmosphere being controlled artifically by the water-jacketed covering. It is desirable that it should be so, since during com-

bustion its temperature will be raised, and if, in its final condition, it be as much warmer than the atmosphere as it was cooler before, the heat losses incident to radiation will be largely nullified. In any case, however, there would remain the question of temperature correction during the period of combustion, when there is a varying rising temperature.

To determine the influence of the atmosphere it becomes necessary, after the bomb has been placed in the water and time allowed for all to average at a common temperature, to wait several minutes, reading the thermometer at each minute interval, in order to find the rate of increasing temperature. Five minutes are usually allowed for this. The preliminary period passed and the weighed sample of fuel ignited exactly at the end of the last minute, it is seen that, until the temperature has risen materially by heat of combustion, some temperature rise is due to atmospheric influence, and hence that a certain negative correction must be made. On the other hand, after the water temperature has risen above that of the atmosphere, a loss outward occurs, the amount of which must be determined by a series of five readings, beginning as soon as the water temperature has reached its maximum and begins to fall. This is known as the final period. During the first part of the combustion period it is necessary to read temperature after the lapse of the first half minute following ignition, in order to fix the rate of increase. If it begins promptly and runs up steadily for the whole of the first minute, one method should be used. If it starts slowly with small increase for a half minute, then mounts quickly during the next period, a somewhat different method should be used, as will appear immediately. If the hand stirring apparatus is used, care should be taken to secure uniform motion.

The record of observation should be preserved in regular form, the following being that employed in the Kansas laboratory:

Preliminary period.	Combustion period.	Final period.
0 ... 25.98	5 ... 26.08	8 ... 28.44
1 ... 26.00	5½ ... 26.50	9 ... 28.43
2 ... 26.03	6 ... 27.80	10 ... 28.42
3 ... 26.05	7 ... 28.40	11 ... 28.42
4 ... 26.07	8 ... 28.44	12 ... 28.41
5 ... 26.08		13 ... 28.41

Total rise 0.10
Rise per min............ 0.020
Observed rise during combustion........... 2.36
Total fall during final period.................................. 0.030
Fall per minute.................................... 0.006

In developing the methods of making corrections to the observed temperature rise, reference may be made to the accompanying illustration (Fig. 2), where the observations during combustion are shown in different form. On the right of the central line are shown actual readings and differences. On the left are the rates of change, the values 0.020 at the 5th minute, and 0.006 at the 8th minute, being those determined as shown above, the latter being a negative increase. Since at the 7th minute the temperature is essentially the same as at the 8th, it may be assumed safely that the temperature effect of the surrounding atmosphere is the same, so that 0.006 is assigned to that minute. This closeness of temperature reading is almost sure to exist at the minute preceding the maximum record, the maximum being sometimes at a 9th minute, occasionally at the 7th, but usually at the 8th. At the 6th minute the rate is an unknown quantity, but is expressed as differing from 0.020 by an amount "x." Similarly, "y" represents the variation at half-minute interval, 5½.

The two following methods of treatment are approximate only, with different degrees of accuracy. They are based on the assumption of uniform rate of temperature rise during isolated minute or half-minute intervals. It is possible to treat the problem with mathematical exactness, but it will be shown that the errors involved in the case are not sufficient to warrant the labor involved.

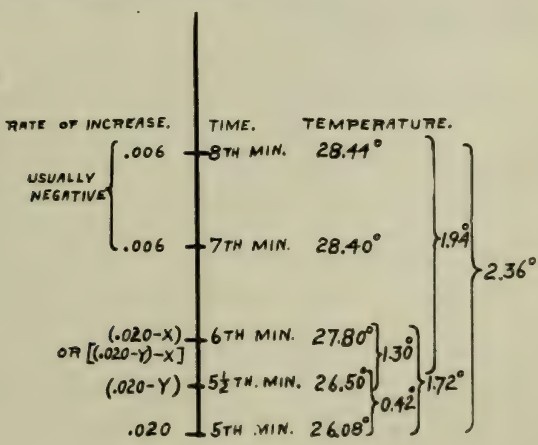


FIG 2. TEMPERATURE RECORD DURING COMBUSTION PERIOD, SHOWING ATMOSPHERIC INFLUENCE.

Using the numerical values of Fig. 2, and making use of the half-minute reading, we may write the proportion:

$$\frac{\text{Change of rate, 5th to } 5\tfrac{1}{2}\text{th}}{\text{Change of rate, 5th to 8th}} = \frac{\text{Change of temperature, 5th to } 5\tfrac{1}{2}\text{th}}{\text{Change of temperature, 5th to 8th}}$$

$$\text{or } \frac{y}{[\,.020-(-.006)\,]} = \frac{0.42}{2.36}$$

$$\text{from which } y = 0.0046$$

Hence "the rate of increase" at '5½' = 0.020 − 0.0046 = .0154°.

Similarly for the half minute, 5½ to 6:

$$\frac{x}{[\,.0154-(-.006)\,]} = \frac{1.30}{1.94}$$

$$\text{or } x, = .0143$$

from which "rate of increase" at "6" = 0.0154 − .0143 = .0011°.

It should be observed here that the maximum temperature of 28.44° is not much above that of the surrounding atmosphere. Had the initial temperature of the water been closer to that of the atmosphere the "rates of increase" at the 5th and 8th minutes would have been more nearly equal, numerically, and at the 6th minute the "rate of increase" would probably be negative. This bears upon a point already mentioned, that the temperature at the beginning should be as much below that of the atmosphere as at the end it is above.

Knowing the "rate of increase" at each division point, we may now find the amount of correction for each interval of time, on the basis of average over a period of uniform rise of temperature, as follows:

$$\text{Increase of temperature during 5 to } 5\tfrac{1}{2} = \frac{0.020 + 0.0154}{2} \times \frac{1}{2} = 0.00885°$$

$$\text{Increase of temperature during } 5\tfrac{1}{2} \text{ to } 6 = \frac{0.0154 + 0.0011}{2} \times \frac{1}{2} = 0.00412°$$

$$\text{Increase of temperature during 6 to 7} = \frac{0.0011 + (-0.006)}{2} = -0.0025°$$

Increase of temperature during 7 to 8 = ... = − 0.0060°

Increase of temperature during 5 to 8, net total . . . . = + 0.0045°

That is, the water of the calorimeter has increased in temperature by 0.0045° due to atmospheric influences, and the net temperature rise due to the heat of combustion of fuel is

$$2.36 - 0.0045 = 2.3555°.$$

This is the corrected temperature rise, which multiplied by the weight of water in grams, gives the amount of heat generated in the bomb.

In the second method we will omit consideration of the half-minute reading at '$5\frac{1}{2}$,' assuming uniform rate of temperature rise from 5 to 6. Our proportion then becomes

$$\frac{x}{[.020-(-006)]} = \frac{1.72}{2.36}$$
$$x = 0.019$$

"Rate of increase" at 6 = .020 — .019 = .001°.

We then have

$$\text{Increase of temperature during 5 to 6} = \frac{0.002 + .001}{2} = 0.0105^\circ$$
$$\text{Increase of temperature during 6 to 7} = \frac{0.001 + (-0.006)}{2} = -0.0025^\circ$$
$$\text{Increase of temperature during 7 to 8} = \ldots\ldots\ldots\ldots = -0.0060^\circ$$
$$\text{Increase of temperature during 5 to 8, net total} \ldots\ldots = 0.0020^\circ$$

The corrected temperature rise on this basis then is

2.36 — 0.0020 = 2.358°.

With water temperatures more evenly divided above and below the atmosphere, the net total increase is usually negative, when it will be added to the observed temperature rise.

Of the two methods the first, obviously, is the more accurate. The difference amounts to 0.00250, or 2700 × 0.0025 = 6.75 calories. The total heat generated is 2700 × 2.3555 = 6359.8 calories. The difference of 6.75 calories thus amounts to 0.106 per cent, or to about one-tenth of one per cent. This is not a large error—in fact, smaller than the experimental error—and when the reading at the $5\frac{1}{2}$th minute is such as to indicate a uniform increase from 5th to 6th, it is permissible to use the shorter method. It was the shorter method that was used in much of the present work, the calculations being usually carried only to .001 place. For illustration, these figures have been carried to the more exact values. It is observed that the total correction of 0.0045 amounts in this case to but two-tenths of one per cent, but under usual conditions of temperature range it is a larger quantity, applied in the opposite direction as above noted. The amount by which the value of .002° is in error, as compared with an absolutely correct solution, is less than the probable errors of observation and measurement.

In following out the calculation partially indicated above,

the sample of coal giving the readings was ignited with a weight of 0.01 gram of iron wire; the titration for nitric acid required 47 c.c. of the sodium carbonate solution; and the analysis showed 4.8 per cent sulphur. The corrections for heat generated thus become

For wire.......... $0.01 \times 1650 =$	16.5	calories.
For nitric acid..................	47.0	"
For sulphur .... $4.8 \times 13.06 =$	62.7	"
Total.................	126.2	"

Corrected heat value $= 6359.8 - 126.2 = 6233.6$ calories per gram,
$= 6233.6 \times 1.8 = 11220.5$ B.t.u. per lb.

The sample was from a coal containing 7.5 per cent moisture so that the heat value per pound of dry coal becomes

$$11220.5 \div 0.925 = 12130 \text{ B. t. u.}$$

Water equivalent of calorimeter parts.

In the sample calculation of heating value from the calorimeter observations, given above, there appears an item representing the effect of those portions of the apparatus which are immersed, and which must conform in temperature to the water. Since this is an item of about 500 grams, to be multiplied by a corrected temperature of from two to four, it is seen that it must be correct to within a few numbers in units place in order to come within the limits of accuracy determined by the other work. Considerable attention has been given to its determination.

The water equivalent of the instrument may be obtained by different methods:

First, by the weights and specific heats of the parts, the water equivalent of the instrument may be calculated. This method was followed out as carefully as conditions would permit, it being impossible, however, to separate entirely some of the platinum and porcelain weights from steel, mercury from glass in the thermometer, etc., and a value was obtained of 536 grams of water. The experimental values show this value to be somewhat high.

Second, by the addition of a measured quantity of water at a known temperature to a quantity of water in the calorimeter at a different temperature, where the value of the calorimeter enters as an unknown quantity, it can be calculated from the resulting temperature. This method, however, is not very satisfactory, on account of the inevitable loss or gain of heat

while pouring the water from one vessel into another. In order to compensate these losses in a measure, it was decided to keep the water in the calorimeter initially at room temperature, and have the water that was poured in for the first trial a number of degrees above, and at the next trial the same number of degrees below, room temperature.

Third, by proportion. This is the most reliable and satisfactory method involving the use of a substance of known heat value. A definite quantity of substance (charcoal in this case) was burned in the bomb, using first a minimum amount of water—that is, just enough to cover the bomb—and then a maximum amount, or as much as the calorimeter bucket would contain. This permitted a difference of 600 grams of water and gave a satisfactory proportion where the water equivalent of the instrument entered as the quantity "x," an unknown. The following is a sample determination:

	Max. water.	Min. water.
Weight of fuel	1.0 gram	1.0 gram
Corrected temperature rise.........	2.227° C.	2.745° C.
Weight of water....................	2700. grams	2100. grams

Extra weight of bomb cap immersed with maximum water, multiplied by specific heat of steel = 14 calories equivalent.

Then $2.227\ (2700+x) - 14 = 2.745\ (2100+x)$
$.518\ x = 6012.9 - 5764.5 + 14 = 262.4$
$x = 507$ grams = water equivalent of instrument.

The average results of twenty-six determinations by these various methods gave the water equivalent of the instrument as 500 grams. This value was used in the calculations of all the heat values of the coals here given.

PRESENTATION OF RESULTS WITH COAL.

In the tables giving the results of the analytical work on coal, the analyses are stated in terms of percentage by weight of the total amount of material included in the determination. This is first done with the full 100 per cent value standing for the original sample as it came from the mine. In the table it is given under the heading of "Moist Coal." The analysis shows all of the four quantities determined; namely, moisture, volatile matter, fixed carbon, and ash.

Due to drying action in the handling of individual samples in the laboratory, and to peculiar conditions under which the

sample might have been taken, the moisture content is likely to vary and to be different from that of the same coal when delivered for use under any given conditions. Since the moisture determination is readily made, it often becomes of value to know how a properly dried sample would analyze. For this reason a second set of results is shown, consisting of the three items; volatile matter, fixed carbon, and ash. It will be observed that these latter quantities are determined by dividing the corresponding quantities in the first analysis by one minus the percentage of moisture.

For purposes of comparison it is very desirable that the analysis of the coal when entirely free from moisture and non-combustible ash be known. For scientific purposes this statement of the analysis is of great value, in that it shows the exact status of the coal according to standard classification. Only the two items, volatile matter and fixed carbon, appear in this statement which occurs in the table under the heading "Combustible." The values here given are determined by dividing the corresponding original values by the quantity remaining when the weights of moisture and ash are deducted from an original unit sample.

In the same table occurs the heat value of the coal as determined by calorimetric test, and it will be observed that this quantity is expressed on the same basis as are the proximate analysis results.

Sulphur content is expressed in terms of moist coal and dry coal only. The present investigation did not enter into the question of the condition of the sulphur content. It may be assumed that it is all combustible, but no special value attaches to its expression in terms of the combustible portion of the coal alone.

It will be observed that the coal from the central Kansas district, in Osage and adjoining counties, is shown to be materially different from the other coals. Particularly does it differ from the general average of the coal from southern Kansas, which latter is the distinctive coal region of the state. This may best be seen by noting the percentage of volatile matter under the heading of "Combustible," where it will be observed that for the central Kansas coals this quantity runs uniformly above 40 per cent. In no case does the coal from southern Kansas show over 39 per cent of volatile matter, and only in occasional instances is that value exceeded in the

Leavenworth district. This difference may be explained by the fact, stated in another part of this bulletin, that the Osage county coal field is well up in the upper coal measures and stratigraphically 2000 feet above the coal of the southern Kansas field. The Leavenworth coal, while lying much deeper below the surface at the point where mined than are the veins at both of the other coal districts, stands between the other two in classification based on percentage of volatile matter. Stratigraphically and by analysis it is closer to the southern Kansas coal.

HEATING VALUE OF OILS.

The calorimetry work on oils, when they are sufficiently heavy to make evaporation losses while weighing the sample negligible, is no different from that on coal. Only traces of sulphur are found, usually. Volatile oils must be run into thin glass bulbs, which are then sealed and weighed, the bulb being broken in the closed bomb by shaking or flattening one side and permiting the pressure to break them. The volatile hydrocarbons produce tremendous and sudden pressures in the bomb if used in the one-gram size of sample common with coal, and hence it is wise to use but approximately one-half gram, with which lower oxygen pressure is permissible. Fifteen atmospheres are sufficient for that weight of combustible, twenty-four or twenty-five being necesary for a full gram of the heavy oils, and eighteen sufficient for common bituminous coal with its high ash and moisture content.

In the accompanying table are given the heating values of twenty-four different crude oils, representing the oil fields of the state. They are arranged in order of density, and it will be noted that this does not accord with geographical distribution, both heavy and light oils occurring in many counties.

In addition to the work with the several crude oils, it has been the purpose to study the characteristics of the various grades given off in the process of fractional distillation. To this end No. 19, an oil close to the average density, was subjected to the distillation process on a 50-degree interval basis, beginning at 150°. That is, all light distillates passing off at a temperature of 150° Centigrade were condensed, a sample preserved of the distillates and another of the residue left in the

still. The temperature was then raised 50 degrees and another pair of samples taken, and so on to the limit. The results of tests on these samples are given in the table with the crude oils, under the headings of "Fuel Oil": "Residues" and "Distillates." The first distillate corresponds roughly to the light naphthas, the second to gasoline, and the third and fourth combined to kerosene. Remaining distillates in the lubricating and polishing classes, which do not split sharply on temperatures, are grouped together as being "heavier than kerosene." Under "Fuel Oil" are listed three oils whose exact origin is unknown, they being oils found by the author in use at as many power plants in the state. These, with No. 3 and No. 4 residue, represent so-called "Fuel Oil" as it has been on the market in the past years.

TABLE OF HEATING VALUES OF KANSAS CRUDE OILS.

No.	Sample from county of	Sp. grav. at 25° C.	Density, Baume.	Heat value per lb. B. t. u.
1	Wilson	.8378	37.1	20915
2	Montgomery	.8413	36.4	19070
3	Chautauqua	.8465	35.4	20490
4	"	.8473	35.2	19744
5	"	.8525	34.2	19577
6	Miami	.8556	33.7	20125
7	"	.8573	33.3	19455
8	Montgomery	.8590	33.0	20085
9	Miami	.8593	32.9	20410
10	Montgomery	.8601	32.8	19500
11	Chautauqua	.8801	29.1	18480
12	Montgomery	.8604	32.7	19200
13	Allen	.8623	32.4	19400
14	Neosho	.8639	32.0	20645
15	Montgomery	.8640	32.0	19510
16	"	.8660	31.6	20630
17	Neosho	.8674	31.4	18670
18	Montgomery	.8706	30.9	19600
19	Neosho	.8722	30.5	19749
20	Allen	.8749	30.0	19530
21	Montgomery	.9030	25.0	19290
22	"	.9110	23.8	17105
23	Wilson	.9340	19.8	18750
24	Coffey	.9340	19.8	19550
	Average, crude oil	.8700	31.0	19560

FUEL OILS.

Residue from Crude Oil No. 19.

1	Distilled at 150° C.	.8730	30.5	19720
2	" " 200° C.	.8870	27.8	19670
3	" " 250° C.	.9010	25.3	19606
4	" " 270° C.	.9250	21.3	19513

Commercial Oils from Miscellaneous Sources.

	Sp. grav. at 25° C.	Density, Baume.	Heat value per lb. B. t. u.
5	.8790	29.3	19186
6	.8870	27.8	19565
7	.8950	26.4	19630
Average of last five	.8970	26.0	19500

Distillates, from Crude Oil No. 19.

At 150° C. and below	.7275	62.5	22020
From 150° to 200°	.7705	51.6	21900
From 200° to 250°	.8060	43.8	21300
From 250° to 300°	.8317	38.3	20700
Mean distillates heavier than kerosene	.8600	37.8	20500

HEATING VALUE OF NATURAL GAS.

The following is given to meet any possible interest in the question, not as representing direct experimental work in heating values, but as calculations from analyses, based on the known calorific values of the constituents. Much of the gas concerned came from Oklahoma, and it represents the midcontinental gas field rather than Kansas. The analyses given in the table on page 9 were all of gas drawn from the pipe line at Lawrence, thus being composite samples from scores of wells scattered through southern Kansas and northern Oklahoma.

For all ordinary commercial work it is sufficiently accurate to consider the entire combustible portion of the gas as methane. The small quantities of other hydrocarbons, differing but little in unit values from methane, and the extremely small amount of carbon monoxide, are not nearly as potent in affecting the value of the gas as are the influences of temperature and pressures, as these properties fluctuate in service with small notice taken by the user. We are thus concerned simply with the properties of pure methane and the percentage of combustible in the gas.

Methane has a heat value of 23,600 British thermal units per pound. At a pressure of four ounces above standard atmospheric pressure and at 60 degrees Fahrenheit a cubic foot of methane gas weighs 0.043 pound, and thus has a heating value of nearly 1015 heat units. Natural gas containing 93 per cent combustible thus may be considered as having

a heat value of 945, and so on. For every degree of temperature of gas below 60 degrees the heat value increases nearly two units. For each additional ounce of pressure the value increases by about four units, or for each additional inch of water pressure by about 2.3 units. With these figures at hand, the change of heat value for minor variations in pressure and temperature may be estimated within a fraction of one per cent error, it being understood that variations in atmospheric pressure must be corrected for, as well as in the observed pressure above atmosphere.

Supplement to Coal Investigations.

By CLARK B. CARPENTER and HUGH R. BROWN.

Senior Students in the School of Engineering.

The work has been done during the school year 1914-'15 as a portion of that necessary in the preparation of a thesis for graduation.

Two methods of taking samples were used, one being essentially the same as that employed during the larger part of the work done by Mr. Bohnstengel, and known as surface or car sampling. The other method is that known as "face" sampling, which is the same as that which was employed by Messrs. Walker and Bohnstengel in the instance discussed in detail on pages 11 to 29. A Mahler bomb calorimeter was employed for the heat determination which was of the same type as that employed in the other work.

The results from the analyses and heat determinations for the nineteen samples are shown in the table designated as Table I at the back of the bulletin. The values correspond in all essential respects with those given in the table prepared by Mr. Bohnstengel, although not showing such wide variations as those found by the latter for the southern coals. In the main the samples are from mines situated at some distance from those examined in the original investigations, with the exception of those in the vicinity of Scammon. In the total, therefore, the fifty-three samples worked upon during the course of the two investigations may be taken as representative of the entire southeastern district of Kansas and to cover that field in a very thorough manner.

Part II.—Sulphur in Bituminous Coal from the Kansas-Missouri Basin.

By Walter Bohnstengel.

SULPHUR DETERMINATION.

When the Mahler bomb calorimeter is used in determining the heat value of coals, it is a simple matter to make a sulphur determination, because the sulphur is oxidized to sulphate and may be precipitated and weighed as barium sulphate.

After firing a sample of coal in the bomb, it is necessary that all the sulphuric acid formed be rinsed into a beaker in order to obtain a true analysis. It has been found that it requires eight to ten rinsings with distilled water, of 15 to 20 c.c. each, to do this. In order to clean the solution of ash and dirt, it is convenient and expedient to pour the rinsings from the bomb through a filter into the beaker. While this order may be varied to suit the convenience of the operator, it is apparent that time may be saved by handling it but once. There should be 200 to 300 c.c. of solution.

After titrating with sodium carbonate for the heat value of nitric acid, the solution is acidified by adding one or two c.c. of concentrated hydrochloric acid, or enough to make it decidedly acid. This is indicated by the returning of the color originally imparted to the rinsings by the addition of methyl orange, before titration. It is then put on the hot plate, allowed to come to boiling, and a liberal excess of barium chloride added slowly, with constant stirring. This barium solution is prepared in accordance with the instructions contained in the following paragraph, and must be heated to a corresponding temperature with the acidified rinsings to which it is added. The mixture is allowed to stand on the hot plate just below the boiling point for an hour or so, or until the precipitate of barium sulphate settles out quickly. After this the clear solution is poured through a washed filter, or a Gooch filter, allowing the precipitate to remain in the bottom of the beaker. This precipitate is then washed several times by decantation and transferred to the filter, and washed with hot water until free from chlorides. The wash water may be tested for chlorides with a

drop of silver nitrate. The filter is then transferred to a weighed crucible, dried, and then burned over a blast burner to constant weight. A second weighing gives, by difference, the weight of barium sulphate, from which the sulphur is found by multiplying by .1373, as seen from the following:

Barium sulphate is made up of the following parts by weight:

Barium	137.4
Sulphur	32.06
Oxygen (four)	64.0
Total	233.46

Then sulphur equals 32.06 divided by 233.46, which equals 0.1373, or 13.73 per cent.

Barium Chloride Solution: A solution of barium chloride containing 20 grams of barium chloride to the liter gives the following results: 137.4 (combining weight of barium) divided by 244.3 (combining weight of barium chloride) equals 56.2 per cent barium in barium chloride; or 20 times 0.562 equals 11.24 grams of barium available. In barium sulphate the sulphur equals 32.06 divided by 137.4, or 23.35 per cent of the barium; or 1000 c.c. of barium chloride solution is sufficient to precipitate 11.24×0.2335 or 2.62 grams of sulphur. Hence a coal containing 5 per cent of sulphur will require nearly 20 c.c. of the above solution for complete precipitation.

A liberal excess of barium chloride does no harm, while an insufficient amount means inaccuracy or extra work; hence it is advisable to add an excess of 50 to 100 per cent over the probable calculations. This means an addition of 30 to 40 c.c. of the solution to the filtrate, and a proportional increase in the amount of time required to filter; hence it is more desirable to use a stronger solution of barium chloride, 30 to 50 grams to the liter being preferable, and add a smaller quantity, about 20 c.c., to precipitate the sulphate.

The washings from the calorimeter were used in the regular sulphur determinations throughout this work, and were checked in a few cases by means of the Eschka method. The results are recorded with the heat values in the main table of results.

SULPHUR BY ESCHKA METHOD.

(Journal American Chemical Society.)

Eschka's method is recommended for most accurate work. The following directions, which are given for the convenience of those using this report, are those by G. L. Heath, with slight modifications:

Mix thoroughly one gram of the finely powdered coal with one gram of magnesium oxide and one-half gram of dry sodium carbonate, in a thin platinum dish having a capacity of 75 to 100 c.c. A crucible may be used, but a dish is preferred. The magnesium oxide should be light and porous, not a compact, heavy variety.

The dish is heated on a triangle over an alcohol lamp, held in the hand at first. Gas must not be used, because of the sulphur it contains. The mixture is frequently stirred with a platinum wire, and the heat is raised very slowly, especially with soft coals. The flame is kept in motion and barely touching the dish, at first, till strong glowing has ceased, and is then increased gradually till in fifteen minutes the bottom of the dish is at a low red heat. When the carbon is burned, transfer the mass to a beaker and rinse the dish, using about 50 c.c. of water. Add 15 c.c. of saturated bromine water and boil for five minutes. Allow it to settle, decant through a filter, boil a second and third time with 30 c.c. of water, and wash till the filtrate gives only a slight opalescence with silver nitrate and nitric acid. The volume of the filtrate should be about 200 c.c. Add $1\frac{1}{2}$ c.c. of concentrated hydrochloric acid, or a corresponding amount of dilute acid (8 c.c. of acid of 8 per cent). Boil till the bromine is expelled, and add to the hot solution, drop by drop, especially at first, and with constant stirring, 10 c.c. of a 10 per cent solution of barium chloride. Digest on the water bath or over a low flame, with occasional stirring, till the precipitate settles clear quickly. Filter and wash, using either a Gooch crucible or a paper filter. The latter may be ignited moist in a platinum crucible, using a low flame until the carbon is burned.

In the case of coals containing much pyrites or calcium sulphate, the residue of magnesium oxide should be dissolved in hydrochloric acid and the solution tested for sulphuric acid.

If desirable, the burning of the coal with Eschka's mixture may be carried on in a muffle, from 20 to 30 minutes being required.

ESTIMATION OF SULPHUR FROM TITRATION WITH SODIUM CARBONATE.

The need for a correction to the apparent heat value, on account of the formation of nitric acid, has been shown. This is done by titrating with a solution of sodium carbonate.

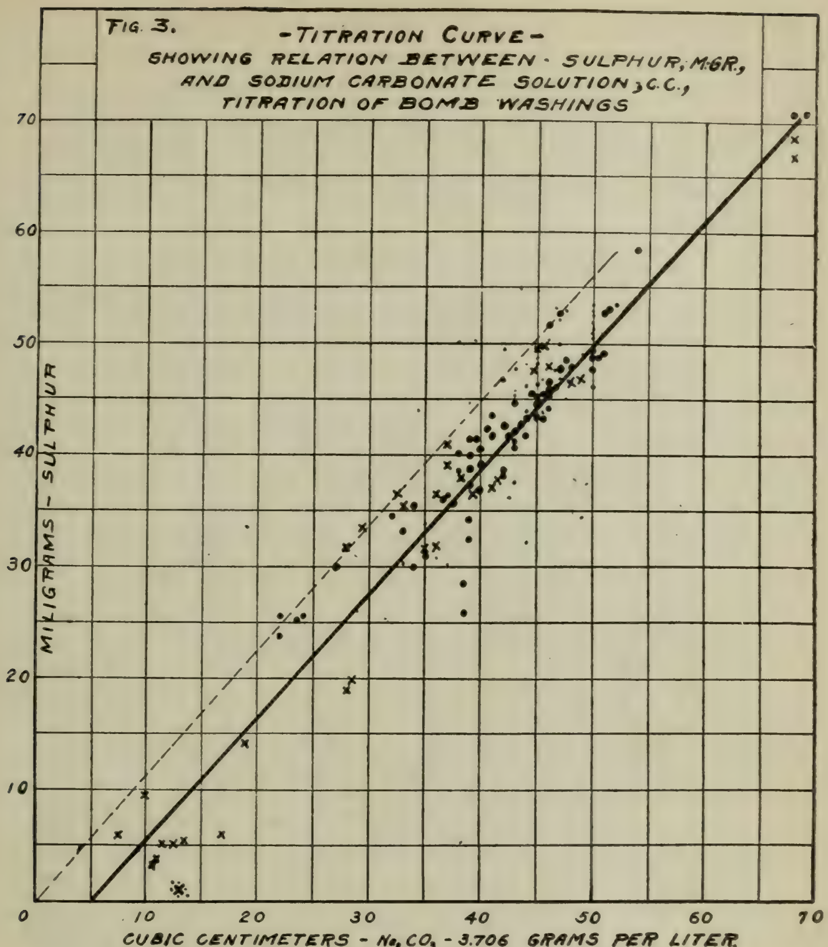
Sodium carbonate was used because it is most convenient for the engineer. A definite amount of chemically pure Na_2CO_3 may be weighed out, and the resulting solution used, where most of the other alkaline reagents would have to be standardized by a process that often requires more time than the analyst wishes to spend. It is not to be understood that a sodium carbonate solution having a certain amount of chemical by weight is an absolute standard, but for the purpose involved the results are well within the experimental errors.

The former discussion also showed that only a part of the alkaline solution was used in neutralizing nitric acid, the remainder being for sulphuric acid formed.

On the accompanying diagram (Fig. 3), the number of cubic centimeters of sodium carbonate solution used in each of many determinations has been plotted as ordinate, and the amount of sulphur contained in the washings, as determined gravimetrically, is shown as abscissa. This was done with the view of getting the total heat correction for both nitric and sulphuric acids by merely titrating the washings, thus avoiding the need of a gravimetric sulphur determination when only the heat value of the fuel is desired.

The dotted curve is based on the chemical relation of sodium carbonate to sulphur as sulphuric acid. Then 50 c.c. of the solution used are equivalent to approximately 56 miligrams of sulphur as sulphuric acid, establishing the slope of the line which represents the relation with no nitric acid at all. The empirical curve is the heavy line to the right, and nearly parallel to the theoretical. The horizontal space between means that a certain amount of the solution (5 to 12 cubic centimeters) is required to neutralize the nitric acid formed, while the remainder is required for the sulphuric acid.

From these curves it is seen that the amount of the heat correction due to both nitric and sulphuric acid may be estimated from the titration values, with results that are well



within the limits of experimental errors of the heat determination. The method is illustrated as follows:

Coal No. 15, in the main table of values, required for neutralization of the acids in rinsings, 42.5 c.c. of the alkaline solution. From the empirical curve in Fig. 3, this corresponds to about 41.5 miligrams, or 4.15 per cent, of sulphur. The heat correction is 4.15 times 13.06, or 54.3 calories. By direct method the sulphur per cent is 4.05, and the heat correction 53 calories. The difference is immaterial from the standpoint of heat value.

The method of making this correction by direct calculation has been shown and discussed in preceding sections of this bulletin.

The variation of the points shows the probable error in finding the true amount of sulphur. It is seen that the actual sulphur in the coal, from the curve, would be subject to considerable per cent variation, depending largely on different coals, but the resulting heat value correction is influenced by a much smaller proportion, and the curve has been found to be very helpful.

Part III. Economic Effects of Washing Coal from the State Mine.

BY

C. M. YOUNG, Associate Professor of Mining Engineering.

The investigations here described were undertaken with the purpose of deciding the possibility of successfully washing coal from the state mine at Lansing, and further, the possibility of so doing it as to make the process financially profitable.

The coal from this mine, when pure—that is, unmixed with foreign substances from the top or bottom, and not including any portion of the coal bed itself which could be considered foreign to the coal substance—has the following compositions:

Moisture	7.87%
Ash	3.21
Fixed carbon	50.68
Volatile and combustible	38.24
	100.00

In this case the sulphur was not determined. These constituents make up the coal itself, and no possible mechanical treatment would reduce either the ash or the sulphur. However, in the process of mining, portions of the rock above and below the coal are included with it, and also portions of the masses of pyrite or iron sulphide which occurs in the coal bed. These two substances constitute the principal impurities, not only in this coal but in others. If the mining of the coal were done by skilled miners in commercial mines it would be possible to eliminate some of these impurities, but under existing conditions it is not reasonable to expect much change in the quality of the coal shipped.

The composition of the coal shipped from the mine varies considerably because of the inclusion with the coal of various amounts of foreign matter. The sample used for the following analysis was taken from bins at the University and represents different shipments, and it probably approaches more nearly the average composition of the coal than any sample which could be obtained away from the mine except by

sampling a large number of shipments over a considerable time.

Ash	16.84%
Fixed carbon	53.46
Volatile and combustible	29.70
	100.00

This sample contains 6.75 per cent sulphur. The heat value was 12780 B. t. u.*

It will be seen that the sulphur is rather high and the ash very high. The latter fact shows that the coal contained considerable amounts of impurities.

Impurities in coal have deleterious effects which may be put under two heads:

First. They have a purely neutral effect, merely replacing a part of the fuel. That is, if the coal contains 15 per cent of impurities its fuel value is only 85 per cent of that of pure coal. The principal effect is upon the freight and labor bills, for it is necessary to pay for freight upon the impurity as well as upon the coal, and to pay for handling it. There is a further effect, in that the impurity has to be heated by the fire, and this heat, which would otherwise be given to the water in the boiler, is lost. If the impurity is volatile it will give up a portion of this heat in passing through the boiler. On the other hand, if it is not volatile the impurity itself will have to be handled as ash, and there will be added expense for this reason. So it is seen that even an impurity not actively harmful has an effect somewhat greater than would be expected from its weight alone.

Second. The impurities are frequently actively harmful. Ash clogs the fire and prevents free burning of the fuel. Frequently it incloses portions of coal, so that a larger part of the fuel goes unburned into the ash than would be the case with pure coal. The ash may be easily fusible, and in this case it will stick to the grate and obstruct the draft, and possibly cause burning of the grates.

* A second determination on a sample taken from the same bins gives a value of 11931. Compare with value for coal No. 64 as given on the large chart prepared by Mr Bonnstengel. Values on the latter chart are determined with the Mahler bomb calorimeter.

The other principal impurity is pyrite or iron sulphide (FeS_2). The sulphur of this substance burns, and the iron appears in the ash. In some cases the iron unites with other constituents of the ash to form an easily fusible slag. The sulphur has some fuel value, but this is more than balanced by the fact that in burning it unites with oxygen to form sulphurous acid and some sulphuric acid. These attack iron exposed to their action wherever the flue gases become cold enough to permit condensation, as sometimes happens in stacks.

Another fact that has had much to do with the development of coal washing is that it is sometimes possible to make metallurgical coke from a coal from which some of the sulphur has been removed by washing, when it would not be possible to do so from the raw coal.

Most washing is done with the aid of water, and the possibility of doing it depends upon the fact that the impurities are heavier than the coal and therefore settle more rapidly in water. The apparatus most used is known as a jig. Jigs for coal washing are of two styles; in both the coal is placed upon a screen to prevent it from falling freely through the water. In one type this screen is given a reciprocating vertical motion; in the other the screen is stationary, while the water is forced up and down by a plunger. In both types the effect is the same. This up-and-down motion through a bed of particles lying in contact with one another produces much the same result as would be gained by placing the coal in a fluid of high specific gravity. In other words, the tendency of some particles to settle more rapidly than others is accentuated, and these fast-settling particles, which in this case are the impurities, collect upon the screen while the coal rises to the top. The various jigs used differ considerably in the methods of removing the waste and coal, but the principle of separating the two products on the screen is the same in all.

A coal washery consists of various machines. First are crushers for reducing the particles to such size that each shall be nearly pure coal or pure refuse. In some cases only the slack produced at the mines is washed, as the lump coal is sufficiently pure.

The crushers are followed by the necessary elevating and conveying machinery to carry the coal to bins. From the

bins it goes—commonly through a mechanical feeder to give steady flow—to the jigs.

The products of the jigs may be simply washed coal and refuse, or in some cases there may be a product which requires rewashing. After jigging the coal is sometimes carried directly to the cars and sometimes separated into various sizes.

The coal-washing plant at the University is made of machinery of commerical size, so arranged and equipped as to be especially flexible, and therefore suitable for the treatment of different coals. The coal is crushed by a toothed roll crusher designed and built at the University. After crushing it is elevated to a revolving screen and separated into three sizes. The coarse coal goes to a jig designed for handling large sizes, the fine coal to a jig suited to the treatment of fine sizes, and the medium size to either jig as desired.

As stated in the opening paragraph, a series of tests was made with coal from the state mine to find whether it could be successfully washed and whether such treatment would be profitable.

THE METHOD FOLLOWED.

Details of one run, No. 5, are given to show the methods followed in the calculations:

RUN NO. 5.

Coal taken from different bins at the University heating plant, giving as nearly an average sample as could be obtained, was crushed and washed in two lots, because the bins at the laboratory would not hold all at once.

		Pounds.	Pounds.
Weight taken—first lot		2756	
second lot		2175	
			4931

Recovery.

	Pounds.		
Coarse washed	1192		
Medium washed	1802		
Fine washed	614		
		3608	

$$\frac{3608 \times 100}{4931} = 73.2\% \text{ washed.}$$

	Pounds.		
Coarse waste	227		
Coarse hutch	75.9		
Medium waste	517		
Medium hutch	191		
Fine hutch No. 1	45.6		
Fine hutch No. 2	16.7		
Fine hutch No. 3	11.1		
Waste from first screen	52		
Waste from second screen	18.6		
Total refuse		1155.2	
Total recovered			4763.2
Lost			167.8

$$\frac{1155.2 \times 100}{4931} = 23.4\% \text{ refuse.}$$

$$\frac{167.8 \times 100}{4931} = 3.4\% \text{ lost.}$$

Somewhat more refuse was recovered than was necessary. This could easily have been avoided on a longer run.

ANALYSES.

(Heat values by Parr Calorimeter.)

	Unwashed coal. Per cent.	Coarse washed. Per cent.	Medium washed. Per cent.	Fine washed. Per cent.
Volatile matter	29.70	35.75	37.59	36.80
Ash	16.84	10.69	8.45	8.20
Fixed carbon	53.46	53.56	53.96	55.00
Sulphur	6.75	4.53	4.04	3.68
Heat value	(a) 12780 (b) 11931*	13706	14530	13750

	Coarse hutch. Per cent.	Medium hutch. Per cent.	Coarse waste (2d lat.). Per cent.	Medium waste. Per cent.	Fine hutch No. 1. Per cent.
Volatile matter	19.28	23.68	17.27	24.37	12.36
Ash	47.15	42.48	39.87	34.50	68.47
Fixed carbon	43.57	33.84	42.86	41.13	19.17
Sulphur	6.04	11.30	23.07	18.75	22.72
Heat value	6485	7575	6045	7418	......

	Fine hutch No. 2. Per cent.	Fine hutch No. 3. Per cent.	Waste from 1st screen. Per cent.	Waste from 2d screen. Per cent.
Volatile matter	23.73	29.42	24.86	29.15
Ash	32.18	19.95	55.53	23.83
Fixed carbon	44.09	50.63	19.61	47.02
Sulphur	7.05	5.80	10.61	7.70
Heat value	9974	12380	4022	10910

Removal of Ash.

Taking ash in coal as 16.84 per cent, we have:

Ash in coal, 4931 × .1684 = 830.2 lbs.

Ash removed:

Coarse waste	227 lbs. × .3987 =	90.5 lbs.
Medium waste	517 lbs. × .3450 =	178.4 lbs.
Coarse hutch	75.9 lbs. × .4715 =	35.8 lbs.
Medium hutch	191.3 lbs. × .4248 =	81.1 lbs.
Fine hutch, No. 1	45.6 lbs. × .6847 =	31.2 lbs.
Fine hutch, No. 2	16.7 lbs. × .3218 =	5.4 lbs.
Fine hutch, No. 3	11.1 lbs. × .1995 =	2.2 lbs.
Waste, first screen	52 lbs. × .5553 =	28.9 lbs.
Waste, second screen	18.6 lbs. × .2383 =	4.4 lbs.
	1155.2 lbs.	457.9 lbs.

$$\frac{457.9 \times 100}{830.2} = 55.2\% \text{ ash removed.}$$

* It is manifest that the heat determination giving 12780 units was in error. A second sample, giving 11931 units, checks closely with the value calculated by the method shown on the following page, and also with coal No. 64 on general chart of values for Kansas coals.

Removal of Sulphur.

The total sulphur in coal washed was estimated in the manner just illustrated for ash, as this was more accurate than finding the amount removed, by multiplying the weight of coal washed by per cent of sulphur found by analysis of sample.

Total sulphur in coal, 351.7 lbs.
Sulphur in washed coal:

Coarse washed	1192 × .0453 = 54.0 lbs.
Medium washed	1802 × .0404 = 72.8 lbs.
Fine washed	614 × .0368 = 22.6 lbs.
	149.4 lbs.

$$\frac{149.4 \times 100}{351.7} = 42.5\%.$$

$$100 - 42.5 = 57.5\% \text{ sulphur removed.}$$

Heat Value in Washed Coal and Heat Value Lost.

(Heat values by Parr calorimeter.)

Total heat value in coal:

Coarse washed	1192 × 13706 = 16338000 B. t. u.
Medium washed	1802 × 14530 = 26183000 B. t. u.
Fine washed	614 × 13750 = 8443000 B. t. u.
Coarse hutch	76 × 6485 = 492800 B. t. u.
Medium hutch	191 × 7575 = 1446700 B. t. u.
Coarse waste	227 × 6045 = 1372100 B. t. u.
Medium waste	517 × 7418 = 3835000 B. t. u.
Fine hutch No. 1	46 × 3000 = 138000 B. t. u. (Assumed.)
Fine hutch No. 2	17 × 9974 = 169560 B. t. u.
Fine hutch No. 3	11 × 12380 = 136190 B. t. u.
Screen waste No. 1	52 × 4022 = 209130 B. t. u.
Screen waste No. 2	19 × 10910 = 207300 B. t. u.
	58970780 B. t. u.

16338000 B. t. u.
26183000 B. t. u.
8443000 B. t. u.

Heat in washed coal, total .... 50964000 B. t. u.

$$\frac{50964000 \times 100}{58970780} = 86.4\%, \text{ total heat value saved.}$$

Loss of heat value is

$$100 - 86.4 = 13.6\%$$

The heat value per pound of the washed coal is

$$\frac{50964000}{3608} = 14123 \text{ B. t. u.}$$

The heat value of the unwashed coal, determined in the same way is

$$\frac{58970780}{4931} = 11960 \text{ B. t. u.*}$$

The heat value of washed coal in terms of that of unwashed coal is

$$\frac{14123}{11960} = 1.1808,$$

or the heat value of the washed coal is 18 per cent more than that of the unwashed coal.

The amount of washed coal equivalent in heat value to any amount of unwashed coal is

$$\frac{11960}{14123} = 84.68\% \text{ (the reciprocal of } 1.1808\text{)}.$$

BOILER-ROOM TESTS.

It was believed necessary to the solution of a part of the problem, viz., the question of the possible saving which would result to the state from the use of washed coal from the state mine at state institutions, that sufficient coal should be washed to permit of running the University power plant on washed coal for several days. Accordingly 61,310 pounds of coal were washed.

The coal was quite dirty, and 26.3 per cent of refuse were removed. This caused the loss of only 5.8 per cent of the heat value.

A calorimeter test made by P. F. Walker showed that the washed coal had a heat value of 22.4 per cent greater than that of unwashed coal.†

A boiler test showed that the evaporating power of the washed coal was 32 per cent greater than that of the unwashed coal. The improvement in evaporating power is greater than that in heat value because the washed coal can be burned more advantageously.

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* Note close check of this value with that determined experimentally with second sample as recorded on preceding pages.

† The lot of washed coal examined at this time for heat value was a different one than that analyzed by Professor Young and reported in the preceding pages. It should be noted that the average heat value of the washed coal as determined by Professor Young, 14123 B. t. u., is 18.1 per cent greater than that of the unwashed coal, taken as 11960, values being based on results by the Parr calorimeter. In this last work on the large lot, determinations were made with the Mahler calorimeter, giving 22.4 per cent increase due to washing. This serves to corroborate the heat values recorded in detail for the first lot, on the basis of using either 11960 or 11931 as heat value of the unwashed coal.—P. F. Walker.

This test shows a greater improvement from washing than could be expected on an average, because the coal used for the test was unusually poor in quality and therefore capable of more than the ordinary improvement.

Having made a considerable number of tests of the washing of this coal, I feel safe in saying that it can be so treated that the washed coal will have an available fuel value at least 15 per cent greater than that of the unwashed coal, ton for ton.

This means that all expenditures for freight for fuel from the state mine would be reduced by 15 per cent. The sum of the freight bills of all institutions for coal from the state mine for the fiscal year ending June 30, 1912, was $32,352.06. Fifteen per cent of this is $4852.80, which amount could be saved on freight by using washed coal.

There is an additional economy in the use of washed coal resulting from the decreased quantity of ash and sulphur in the coal, which would probably amount to 3 per cent. This should be added to the saving in freight, making a total saving of 18 per cent, or $5823.36.

No account is here taken of the saving in cost of transportation from the railroad to the place of consumption, as no figures were available, except in the case of the University. The University was then paying 50 cents per ton for haulage, and the saving in this item, reckoned as 18 per cent of the haulage cost, would be $671.56, thus making the saving on transportation for the University alone $1180.22 per year.

Another matter, which may be of considerable importance in some cases, is the fact that the better behavior of washed coal on the grates will permit the development of about 20 per cent more power with the same equipment than can be developed with unwashed coal from the state mine.

The machinery and material for a washery to handle the output of the state mine would cost, delivered at Lansing, possibly $30,000, probably less. It is impossible to give an exact statement of the cost, as this can be learned only by submitting bids. As the building could be erected and the machinery installed by prison labor, this figure will cover the cost of the washery.

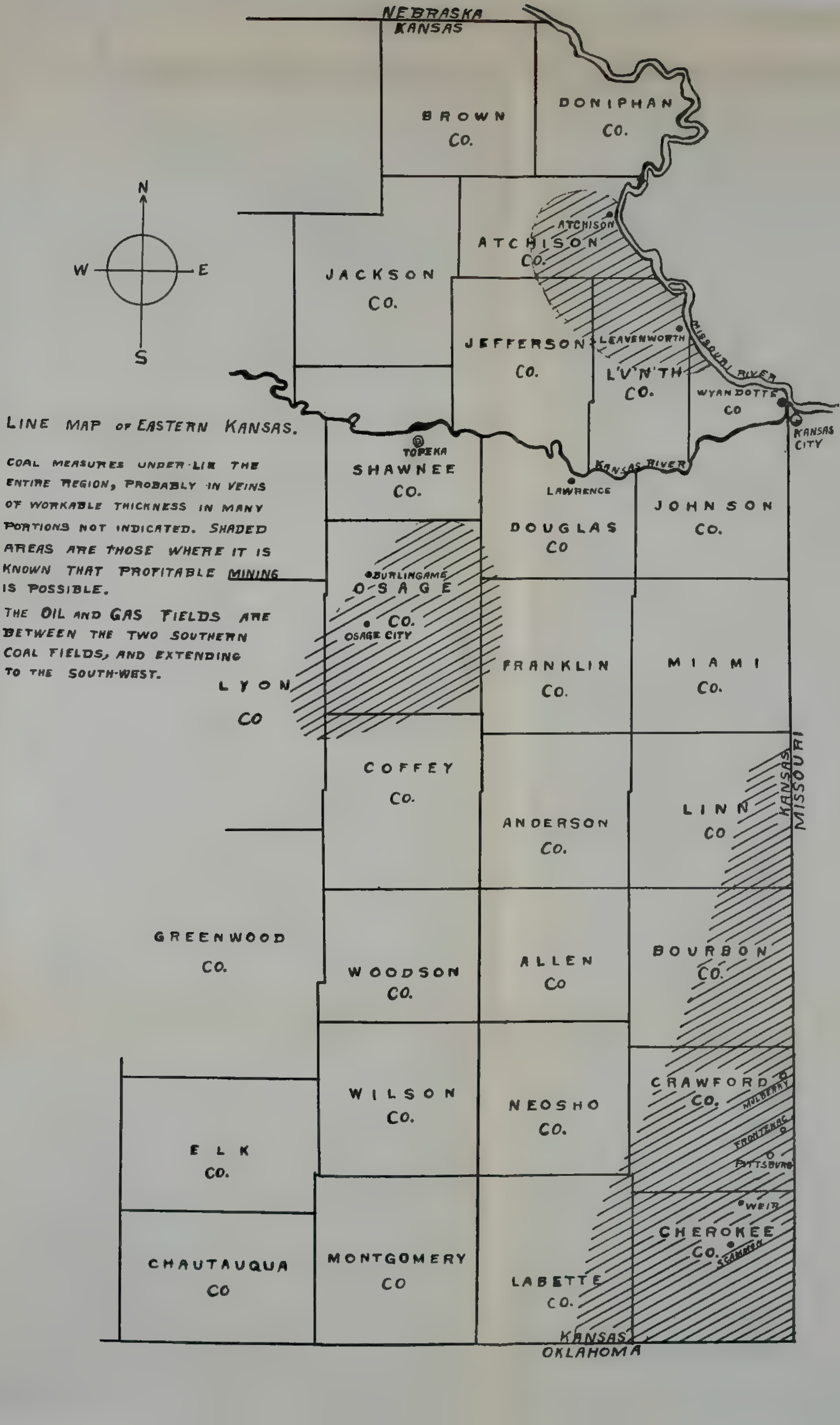
The saving in freight as above quoted, \$5823.36, is 19.4 per cent of \$30,000. In other words, if we allow 4 per cent interest on the investment, there will remain 15.4 per cent to be distributed among depreciation, running expenses and profits. If it is assumed that repairs and expenses will amount to 10 per cent, there is still left 5.4 per cent to be applied to amortization. Probably it would be possible to finance the plant in such a way as to make it pay for itself in less than the time indicated by these figures.

TABLE 1

ANALYSIS OF SOUTHEASTERN KANSAS COALS By C.B. Carpenter and H.R. Brown

Lawrence, Kansas. 1914-15.

Sample No.	Moist Coal Per Cent					Dry Coal Per Cent				Combustible			Heat Value B.T.U's Per Pound			Per Cent Combustible in Moist Coal	Remarks	
	Moisture	Volatile Matter	Fixed Carbon	Ash	Total	Volatile Matter	Fixed Carbon	Ash	Total	Volatile Matter	Fixed Carbon	Total	Moist Coal	Dry Coal	Combustible			
1	3.47	32.69	54.72	9.12	100.00	33.86	56.68	9.46	100.00	37.39	62.61	100.00	12800	13360	14750	87.41	Skidmore	Shovel
2	1.87	33.95	48.61	15.57	100.00	34.59	49.52	15.88	100.00	41.12	58.88	100.00	12000	12220	14530	82.56	Skidmore	"
3	2.18	35.27	50.49	12.06	100.00	36.05	51.61	12.34	100.00	41.13	58.87	100.00	12700	12980	14810	85.76	Steppville	Shaft
4	2.41	34.99	53.72	8.88	100.00	35.86	55.04	9.10	100.00	39.45	60.55	100.00	13400	13730	15100	88.71	Skidmore	"
5	2.16	31.91	48.26	17.67	100.00	32.61	49.33	18.06	100.00	39.79	60.21	100.00	11000	11240	13720	80.17	Scammon.	"
6	2.44	30.54	47.40	19.62	100.00	31.30	48.59	20.11	100.00	39.18	60.82	100.00	11600	11890	14880	77.94	Scammon.	"
7	1.78	34.11	51.05	13.06	100.00	34.72	51.96	13.32	100.00	40.05	59.95	100.00	12700	12930	14910	85.16	Scammon.	"
8	2.24	33.58	50.92	13.26	100.00	34.35	52.08	13.57	100.00	39.74	60.26	100.00	12000	12280	14220	84.50	West Mineral	"
9	1.88	34.86	48.58	14.68	100.00	35.42	49.51	15.07	100.00	41.70	58.30	100.00	12600	12840	15100	83.44	Roseland.	"
10	1.92	34.25	50.03	13.80	100.00	34.92	51.01	14.07	100.00	40.64	59.36	100.00	12900	13150	15310	84.28	Radley	"
11	2.39	33.22	48.96	15.43	100.00	34.03	50.16	15.81	100.00	40.42	59.58	100.00	12200	12490	14840	82.18	Radley	"
12	2.10	34.18	48.80	14.92	100.00	34.91	49.95	15.14	100.00	41.14	58.86	100.00	12400	12760	15010	82.98	Radley	"
13	2.84	33.43	49.15	14.58	100.00	34.41	50.59	15.00	100.00	40.48	59.52	100.00	12500	12760	15060	82.58	Ringo	"
14	1.73	34.38	51.30	12.58	100.00	34.98	52.20	13.82	100.00	39.43	60.57	100.00	12800	13020	14930	85.68	Ringo	"
15	2.14	35.63	51.36	10.87	100.00	36.41	52.47	11.12	100.00	40.97	59.03	100.00	13080	13370	15040	86.99	Edson	"
16	3.41	35.58	53.70	7.31	100.00	36.83	55.59	7.58	100.00	39.85	60.15	100.00	13500	13970	15120	89.28	Edson.	Washery
17	3.16	32.61	49.74	14.49	100.00	33.67	51.36	14.97	100.00	39.59	60.41	100.00	12200	12590	14810	82.35	Franklin	Shaft
18	1.45	38.49	48.88	11.18	100.00	39.06	49.59	11.35	100.00	44.06	55.94	100.00	12500	12680	14300	87.37	Franklin	"
19	3.17	35.96	47.72	13.15	100.00	37.13	49.28	13.59	100.00	42.96	57.04	100.00	12700	13110	15170	83.68	Breezy Hill.	"



LINE MAP OF EASTERN KANSAS.
COAL MEASURES UNDER-LIE THE ENTIRE REGION, PROBABLY IN VEINS OF WORKABLE THICKNESS IN MANY PORTIONS NOT INDICATED. SHADED AREAS ARE THOSE WHERE IT IS KNOWN THAT PROFITABLE MINING IS POSSIBLE.
THE OIL AND GAS FIELDS ARE BETWEEN THE TWO SOUTHERN COAL FIELDS, AND EXTENDING TO THE SOUTH-WEST.
N
S
E
W
NEBRASKA
KANSAS
BROWN CO.
DONIPHAN CO.
ATCHISON CO.
ATCHISON
JACKSON CO.
JEFFERSON CO.
LEAVENWORTH
L'V'N'TH CO.
MISSOURI RIVER
WYANDOTTE CO
KANSAS CITY
TOPEKA
SHAWNEE CO.
KANSAS RIVER
LAWRENCE
DOUGLAS CO
JOHNSON CO.
BURLINGAME
OSAGE CO.
OSAGE CITY
LYON CO
FRANKLIN CO.
MIAMI CO.
COFFEY CO.
ANDERSON CO.
LINN CO
KANSAS
MISSOURI
GREENWOOD CO.
WOODSON CO.
ALLEN CO
BOURBON CO.
WILSON CO.
NEOSHO CO.
CRAWFORD CO.
MULBERRY
FRONTENAC
PITTSBURG
ELK CO.
WEIR
CHEROKEE CO.
SCAMMON
CHAUTAUQUA CO
MONTGOMERY CO
LABETTE CO.
KANSAS
OKLAHOMA

COAL ANALYSIS
UNIVERSITY OF KANSAS.
DETERMINATIONS AND CALCULATIONS
-BY-

WALTER BOHNSTENGEL.

Lawrence Kansas 1910-11.

No.	Heat Value. B.T.U's Per Pound. Moist Coal	Dry Coal.	Combustible	Per Cent Combustible in Moist Coal	Proximate Analysis. Values In Per Cent. Moist Coal: Moisture	Volatile Matter	Fixed Carbon	Ash	Total.	Dry Coal. Volatile Matter	Fixed Carbon	Ash	Total	Combustible. Volatile Matter	Fixed Carbon	Total.	Sulphur Per Cent. Moist Coal	Dry Coal.	Na_2CO_3 c.c. per gram coal	Remarks. Numbers indicate duplicate samples	Locality.
					SOUTHERN					KANSAS				COALS.							
1.	13385	13675	14740	90.80	2.20	34.15	56.75	6.90	100.00	34.95	58.00	7.05	100.00	37.60	62.40	100.00	2.65	2.71	38.5		PITTSBURG.
2.	12710	13220	14850	85.60	3.90	29.50	56.10	10.50	100.00	30.70	58.30	11.00	100.00	34.50	65.50	100.00	3.58	3.72	39.5	See Nº 27.	SCAMMON
3.	13030	13195	14320	90.95	1.30	33.50	57.45	7.75	100.00	33.95	58.20	7.85	100.00	36.85	63.15	100.00	3.02	3.05	34.5		WEIR CITY JUNCTION.
4.	12945	13195	14320	90.35	2.00	32.85	57.50	7.65	100.00	33.50	58.70	7.80	100.00	36.40	63.60	100.00	3.28	3.34	39.0		FLEMING.
5.	13015	13175	14400	90.25	1.20	32.15	58.10	8.55	100.00	32.50	58.85	8.65	100.00	35.70	64.30	100.00	4.76	4.82	50.0		FRONTENAC
6.	12880	13030	14440	89.10	1.15	31.90	57.20	9.75	100.00	32.25	57.85	9.90	100.00	35.75	64.25	100.00	3.70	3.75	37.5		FLEMING
7.	12845	12995	14340	89.65	1.10	31.70	57.95	9.25	100.00	32.00	58.65	9.35	100.00	35.35	64.65	100.00	4.06	4.11	43.0		SCAMMON.
8.	12765	12940	14130	90.30	1.45	29.85	60.45	8.25	100.00	30.35	61.30	8.35	100.00	33.05	66.95	100.00	3.79	3.85	42.0	See Nº 32.	FRONTENAC.
9.	12505	12655	14210	88.00	1.25	31.10	56.90	10.75	100.00	31.50	57.60	10.90	100.00	35.30	64.70	100.00	4.32	4.38	46.0		SCAMMON.
10.	12230	12650	14680	83.25	2.55	27.65	55.60	14.20	100.00	28.40	57.00	14.60	100.00	33.20	66.80	100.00	3.41	3.50	33.0	See Nº 25.	SCAMMON
11.	12105	12570	14630	82.75	3.70	29.50	53.25	13.55	100.00	30.60	55.30	14.10	100.00	35.60	64.40	100.00	4.16	4.33	43.0	See Nº 34.	WEIR
12.	12235	12550	13950	87.75	1.75	32.50	55.25	10.50	100.00	33.05	56.25	10.70	100.00	37.05	62.95	100.00	4.01	4.08	38.5		SCAMMON
13.	12335	12535	14060	87.75	1.65	33.80	53.95	10.60	100.00	34.40	54.85	10.75	100.00	38.60	61.40	100.00	4.83	4.91	50.5		HUMBLE
14.	12155	12495	14830	81.90	2.75	28.60	53.30	15.35	100.00	29.35	54.80	15.85	100.00	34.90	65.10	100.00	4.56	4.68	47.0	See Nº 31.	FRONTENAC
15.	11970	12480	14660	81.60	4.10	28.40	53.20	14.30	100.00	29.60	55.55	14.85	100.00	34.80	65.20	100.00	4.05	4.23	42.5	See Nº 29.	PITTSBURG SOUTH
16.	12210	12365	13900	87.80	1.30	31.20	56.60	10.90	100.00	31.60	57.35	11.05	100.00	35.50	64.50	100.00	6.98	7.07	68.5		FLEMING
17.	12120	12260	14340	84.45	1.15	31.00	53.45	14.40	100.00	31.40	54.10	14.50	100.00	36.70	63.30	100.00	4.48	4.54	45.0		SCAMMON
18.	12050	12175	14230	84.70	1.05	32.05	52.65	14.25	100.00	32.40	53.20	14.40	100.00	37.85	62.15	100.00	4.81	4.86	49.0		PITTSBURG SOUTH
19.	11970	12115	14260	83.95	1.25	29.55	54.40	14.80	100.00	29.95	55.05	15.00	100.00	35.20	64.80	100.00	4.17	4.23	43.0		FLEMING.
20.	11495	12090	14700	78.05	4.95	27.55	50.50	17.00	100.00	29.00	53.20	17.80	100.00	35.30	64.70	100.00	5.29	5.56	51.0	See Nº 30.	SCAMMON
21.	11910	12085	13900	85.70	1.50	30.75	54.95	12.80	100.00	31.20	55.80	13.00	100.00	35.85	64.15	100.00	4.27	4.33	44.5	See Nº 24.	FRONTENAC
22.	11895	12065	14500	81.90	1.40	29.90	52.00	16.70	100.00	30.30	52.75	16.95	100.00	36.50	63.50	100.00	3.98	4.03	39.5		MULBERRY
23.	11790	12015	13860	85.00	1.90	33.75	51.25	13.10	100.00	34.45	52.25	13.30	100.00	39.70	60.30	100.00	4.42	4.51	45.0		SCAMMON
24.	11820	11975	14170	83.40	1.25	30.60	52.80	15.35	100.00	31.00	53.45	15.55	100.00	36.70	63.30	100.00	5.22	5.29	51.0	See Nº 21.	FRONTENAC
25.	11800	11965	13950	84.60	1.40	31.40	53.20	14.00	100.00	31.80	53.95	14.25	100.00	37.10	62.90	100.00	4.62	4.69	46.5	See Nº 10.	SCAMMON
26.	11770	11905	13660	86.10	1.15	31.55	54.55	12.75	100.00	31.95	55.15	12.90	100.00	36.65	63.35	100.00	3.85	3.90	39.5		WEIR CITY
27.	11565	11790	14100	82.00	1.90	29.75	52.25	16.10	100.00	30.30	53.25	16.45	100.00	36.30	63.70	100.00	3.55	3.61	37.5	See Nº 2.	SCAMMON
28.	11535	11690	14340	80.35	1.40	28.30	52.05	18.25	100.00	28.75	52.75	18.50	100.00	35.20	64.80	100.00	4.30	4.36	41.0		FLEMING
29.	11275	11465	13950	80.70	1.65	30.70	50.00	17.65	100.00	31.20	50.85	17.95	100.00	38.05	61.95	100.00	4.48	4.56	46.0	See Nº 15.	PITTSBURG SOUTH
30.	11025	11175	13850	79.60	1.40	28.80	50.80	19.00	100.00	29.30	51.40	19.30	100.00	36.30	63.70	100.00	4.15	4.21	41.5	See Nº 20.	SCAMMON
31.	11050	11160	14040	78.65	1.00	29.10	49.55	20.35	100.00	29.35	50.10	20.55	100.00	37.00	63.00	100.00	4.14	4.18	39.0	See Nº 14.	FRONTENAC
32.	10930	11070	13890	78.75	1.25	28.90	49.85	20.00	100.00	29.30	50.45	20.25	100.00	36.70	63.30	100.00	4.19	4.24	40.0	See Nº 8.	FRONTENAC
33.	10150	10325	14160	71.65	1.70	26.75	44.90	26.65	100.00	27.25	45.65	27.10	100.00	37.35	62.65	100.00	2.49	2.53	23.5		FLEMING
34.	9935	10080	14000	70.80	1.40	28.15	42.65	27.80	100.00	28.60	43.20	28.20	100.00	39.80	60.20	100.00	2.42	2.46	22.0	See Nº 11. SAMPLE FROM LOADED CAR.	WEIR
					CENTRAL					KANSAS				Coals							
35.	11245	11995	12930	87.00	6.25	35.20	51.80	6.75	100.00	37.55	55.25	7.20	100.00	40.40	59.60	100.00	3.14	3.35	45.0		FOSTORIA
36.	11160	11980	12960	86.05	6.75	36.90	49.15	7.20	100.00	39.60	52.70	7.70	100.00	42.90	57.10	100.00	3.43	3.67	43.0		OSAGE CITY.
37.	11120	11790	12860	86.50	5.60	36.50	50.00	7.90	100.00	38.70	52.95	8.35	100.00	42.20	57.80	100.00	4.80	5.09	50.0		FOSTORIA.

31.	11050	11160	14040	78.65	1.00	29.10	49.55	20.35	100.00	29.35	50.10	20.55	100.00	37.00	63.00	100.00	4.14	4.18	39.0	See № 14. FRONTENAC
32.	10930	11070	13890	78.75	1.25	28.90	49.85	20.00	100.00	29.30	50.45	20.25	100.00	36.70	63.30	100.00	4.19	4.24	40.0	See № 8. FRONTENAC
33.	10150	10325	14160	71.65	1.70	26.75	44.90	26.65	100.00	27.25	45.65	27.10	100.00	37.35	62.65	100.00	2.49	2.53	23.5	FLEMING
34.	9935	10080	14000	70.80	1.40	28.15	42.65	27.80	100.00	28.60	43.20	28.20	100.00	39.80	60.20	100.00	2.42	2.46	22.0	See № 11. WEIR SAMPLE FROM LOADED CAR.
					CENTRAL KANSAS COALS															
35.	11245	11995	12930	87.00	6.25	35.20	51.80	6.75	100.00	37.55	55.25	7.20	100.00	40.40	59.60	100.00	3.14	3.35	45.0	FOSTORIA
36.	11160	11980	12960	86.05	6.75	36.90	49.15	7.20	100.00	39.60	52.70	7.70	100.00	42.90	57.10	100.00	3.43	3.67	43.0	OSAGE CITY.
37.	11120	11790	12860	86.50	5.60	36.50	50.00	7.90	100.00	38.70	52.95	8.35	100.00	42.20	57.80	100.00	4.80	5.09	50.0	FOSTORIA.
38.	10940	11730	12710	86.10	6.70	35.65	50.45	7.20	100.00	38.25	54.05	7.70	100.00	41.40	58.60	100.00	4.33	4.65	46.0	BURLINGAME.
39.	10905	11630	12760	85.45	6.25	36.00	49.45	8.30	100.00	38.45	52.70	8.85	100.00	42.15	57.85	100.00	4.74	5.06	44.5	"
40.	11015	11620	12830	85.85	5.15	37.25	48.60	9.00	100.00	39.30	51.25	9.45	100.00	43.40	56.60	100.00	4.48	4.73	47.0	"
41.	10645	11535	12670	84.05	7.75	36.00	48.05	8.20	100.00	39.05	52.05	8.90	100.00	42.80	57.20	100.00	4.34	4.73	44.0	OSAGE CITY
42.	10930	11520	12870	84.95	5.10	36.85	48.10	9.95	100.00	38.80	50.75	10.45	100.00	43.40	56.60	100.00	5.02	5.30	51.0	FOSTORIA.
43.	10650	11495	12780	83.30	7.45	35.90	47.50	9.15	100.00	38.80	51.35	9.85	100.00	43.00	57.00	100.00	3.59	3.88	39.5	OSAGE CITY.
44.	10620	11440	12790	83.00	7.15	34.25	48.75	9.85	100.00	36.95	52.50	10.55	100.00	41.30	58.70	100.00	4.22	4.55	43.0	FOSTORIA
45.	10465	11370	12730	82.15	8.00	30.80	51.35	9.85	100.00	33.50	55.80	10.70	100.00	37.50	62.50	100.00	4.44	4.82	45.0	OSAGE CITY
46.	10590	11365	12550	84.30	6.95	35.25	49.05	8.75	100.00	37.90	52.70	9.40	100.00	41.80	58.20	100.00	4.87	5.24	50.0	FOSTORIA
47.	10515	11335	12560	83.65	7.30	33.70	39.95	9.05	100.00	36.35	53.90	9.75	100.00	40.30	59.70	100.00	2.90	3.12	38.5	BURLINGAME
48.	10565	11225	12630	83.55	5.90	35.00	48.55	10.55	100.00	37.15	51.65	11.20	100.00	41.90	58.10	100.00	4.57	4.85	45.0	"
49.	10365	11220	12320	84.05	7.65	34.90	49.15	8.30	100.00	37.85	53.20	8.95	100.00	41.55	58.45	100.00	3.32	3.60	49.0	OSAGE CITY.
50.	10215	11050	12440	82.05	7.50	32.45	49.60	10.45	100.00	35.10	53.65	11.25	100.00	39.50	60.50	100.00	4.09	4.42	46.0	OSAGE CITY.
51.	9650	10325	12000	80.40	6.50	36.20	44.20	13.10	100.00	38.65	47.30	14.05	100.00	45.05	54.95	100.00	6.09	6.52	59.0	BURLINGAME.
					LEAVENWORTH COALS.															
52.	13300	13655	14580	91.20	2.60	37.75	53.45	6.20	100.00	38.75	54.85	6.40	100.00	41.40	58.60	100.00	2.97	3.05	36.5	HAND PICKED SAMPLES.
53.	13250	13515	14580	90.90	1.90	37.90	53.00	7.20	100.00	38.60	54.05	7.35	100.00	41.70	58.30	100.00	2.49	2.56	30.5	NOT REPRESENTATIVE.
54.	11695	12675	14560	80.25	7.75	31.45	48.80	12.00	100.00	34.10	52.90	13.00	100.00	39.10	60.90	100.00	4.27	4.63	39.0	
55.	11647	12663	14450	80.55	8.05	32.15	48.40	11.40	100.00	34.90	52.65	12.45	100.00	39.85	60.15	100.00	4.15	4.51	35.7	
56.	11670	12640	14400	81.00	7.70	31.45	49.55	11.30	100.00	34.05	53.65	12.30	100.00	38.85	61.15	100.00	4.85	5.25	41.5	
57.A.	11500	12590	13930	82.55	8.65	32.35	50.20	8.80	100.00	35.40	54.95	9.65	100.00	39.20	60.80	100.00	3.97	4.35	42.0	A · Fine Ground.
57B.	11750	12630	13940	84.30	6.90	32.35	51.95	8.80	100.00	34.75	55.80	9.45	100.00	38.40	61.60	100.00	4.06	4.36	45.0	B - Sifted · 100 Mesh.
58.	11385	12475	14370	79.10	8.80	30.85	48.25	12.10	100.00	33.90	52.90	13.20	100.00	39.05	60.95	100.00	4.94	5.40	45.0	
59.	11365	12215	14200	79.95	7.00	30.75	49.20	13.05	100.00	33.05	52.90	14.05	100.00	38.40	61.60	100.00	4.76	5.12	41.0	
60.A.	11260	12250	13800	81.55	8.15	31.70	49.85	10.30	100.00	34.55	54.25	11.20	100.00	38.90	61.10	100.00	4.30	4.68	45.5	FOR EXPLANATION OF
60.B.	11210	12130	13810	81.05	7.65	31.40	49.65	11.30	100.00	34.00	53.75	12.25	100.00	38.70	61.30	100.00	4.70	5.09	47.0	SAMPLES 55, 56, 57, 59,
61.A	11070	12160	13840	80.00	9.00	32.20	47.80	11.00	100.00	35.35	52.60	12.05	100.00	40.25	59.75	100.00	4.78	5.25	48.0	60, 61, 62, AND 65, SEE REPORT ON "SPECIAL
61.B.	11110	12030	13620	81.50	7.60	32.30	49.20	10.90	100.00	35.00	53.25	11.75	100.00	39.65	60.35	100.00	4.82	5.22	47.0	SAMPLES FROM A
62.A.	10960	12040	13810	79.30	9.10	31.55	47.75	11.60	100.00	34.75	52.50	12.75	100.00	39.80	60.20	100.00	4.79	5.27	47.0	SINGLE MINE" IN
62.B.	11050	11960	13720	80.50	7.60	32.70	47.80	11.90	100.00	35.40	51.75	12.85	100.00	40.70	59.30	100.00	4.89	5.29	48.5	THE PRECEEDING PAGES.
63.	11475	11830	13740	83.50	2.95	35.30	48.20	13.55	100.00	36.40	49.65	13.95	100.00	42.30	57.70	100.00	4.80	4.95	50.0	
64.	11460	11810	13580	84.35	3.00	33.65	50.70	12.65	100.00	34.70	52.25	13.05	100.00	39.85	60.15	100.00	4.95	5.11	50.0	64, 66, AND 67 ARE SAMPLES FROM MINE-RUN
65.	10220	11130	14340	71.20	8.25	29.00	42.20	20.55	100.00	31.60	46.00	22.40	100.00	40.75	59.25	100.00	4.50	4.90	40.0	COAL DELIVERED TO
66.	10070	10380	12730	79.10	3.05	33.35	45.75	17.85	100.00	34.40	47.20	18.40	100.00	42.20	57.80	100.00	4.66	4.81	44.0	UNIVERSITY FROM STATE
67.	9975	10370	12840	77.30	3.80	31.50	45.80	18.90	100.00	32.75	47.60	19.65	100.00	40.75	59.25	100.00	5.14	5.34	50.0	PENITENTIARY MINE. LANSING.

BULLETIN OF THE UNIVERSITY OF KANSAS.

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ENGINEERING BULLETIN No. 7.

BULLETIN No. 1.

DIVISION OF STATE CHEMICAL RESEARCH,

W. A. WHITAKER, *Director*.

THE REMOVAL OF IRON FROM MUNICIPAL WATER SUPPLIES,

BY

JAMES W. SCHWAB.

LAWRENCE, KANSAS.

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of Engineering Departments.

The Station designs to issue bulletins, of which this is the seventh number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, and other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletins will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

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Included in the Department of Chemistry is the Division of State Chemical Research, which has for its object the study of those problems of Kansas, municipal or industrial, which may lend themselves to chemical investigation. In addition to its own problems, this division coöperates with other University activities which are engaged in state service work.

THE UNIVERSITY OF KANSAS.

ENGINEERING EXPERIMENT STATION

BULLETIN NO. 7. APRIL, 1915.

The Removal of Iron From Municipal Water Supplies,

BY JAMES W. SCHWAB.

BULLETIN NO. 1.

DIVISION OF STATE CHEMICAL RESEARCH,

W. A. WHITAKER, *Director*.

CONTENTS.

THE REMOVAL OF IRON FROM MUNICIPAL WATER SUPPLIES.

INTRODUCTION.

IRON is one of the most undesirable constituents which may exist in ground waters, for the reason that relatively small amounts may render the water unfit for general use. Many water supplies, which are satisfactory in other respects, are objectionable on account of small quantities of dissolved iron. Such a condition is usually regarded as a thing to be endured only temporarily, with the hope that some relief may be obtained from a new supply or by some method of iron removal.

Waters containing iron, when freshly drawn from the well, are usually clear and sparkling and attractive in appearance. They have a peculiar inky taste, but this ceases to be disagreeable on acquaintance. After the water has been in contact with the air for a few minutes it becomes opalescent, then quite yellow and turbid, resembling the water from a muddy river. On standing awhile it grows darker in color, having a brownish-red cast. After several days have elapsed the brown sediment settles out, leaving the water clear and free from the iron.

When a city is supplied with such a water, the supply receives usually no other treatment than a short period of sedimentation before it is delivered to the consumer. A yellow precipitate is deposited in the distribution system. A part of this precipitate forms a scale and diminishes the flow of water in the pipes, while the remainder is carried on to the tap of the consumer. At this stage the most objectionable features of an iron water make their appearance. White plumbing fixtures are discolored and stained with rust, and clothes laundered in the water are covered with brownish-red spots; in fact, in all cleansing operations the precipitated iron is likely to cause rust spots, and especially in those operations in which soap or alkalies are used. Coffee and tea made with the water have a muddy appearance and a disagreeable inky taste. Vegetables and other foods cooked in it acquire a reddish color. Its objectionable appearance renders it undesirable for drinking purposes.

For many industrial uses, water containing even as much as 1 p. p. m.[1] of iron must be purified. It can not be used in dye works unless the iron has been removed.[2] It can not be used in the manufacture of paper, as the iron precipitates on the pulp, imparting to it a brown color and also causing spotty effects during sizing or tinting. Iron water can not be used in bleaching fabrics, because salts which spot the goods are formed. Iron forms dark-greenish and black compounds with tannin, which discolor hides in tanning and barley in malting.

There are other troubles which may, and usually do, occur when a water containing iron is used. Such waters have a high carbon dioxide content, which causes them to be corrosive. This action is noticed by the average consumer on the small, light pipes used in the plumbing fixtures. The corrosive action of the carbon dioxide is such that these pipes fall to pieces every few years and must be replaced. Leaks caused by corroded valve seats are a constant source of annoyance and expense.[3]

Another source of great annoyance in a water which contains iron is that such waters form the ideal medium for the growth of *Crenothrix polyspora* and other iron-bearing bacteria. *Crenothrix* belongs to the class of higher bacteria. The individual cells are rectangular in shape and grow in long threads or chains, which are surrounded by a gelatinous sheath.[4] In the very young organisms the sheath is transparent, but soon iron hydroxide is precipitated in the sheath and the thread turns yellow, and later a dirty brown.

Some of these iron bacteria have been grown successfully in organic media containing no iron, manganese or aluminum,[5] but they are never found in nature except in waters containing salts of these metals in solution. Each species precipitates the hydroxide of one of these metals. The species which precipitate iron, of which there are several, are the most common. These bacteria grow best in the dark, in a water containing little dissolved oxygen and large quantities of free carbon dioxide. They multiply very rapidly when conditions are suitable, rapidly clogging the wells, and growing luxuriantly in covered reservoirs and in the pipes of

1. P. p. m. = parts per million.

2. Rawson, A Manual of Dyeing (1910).

3. It is the opinion of Prof. C. C. Young that corroded valve seats cost each Lawrence water consumer one dollar per year.

4. D. D. Jackson, Trans. Am. Mic. Soc., 23-31.

5. Molisch, Die Eisenbakterien. Jena (1910).

the distribution system. Threads and bunches of these bacteria are washed loose from the pipes and are carried on to the consumer in slimy masses, during periods of greatest growth, in such quantities as to stop up the strainers in the meters.[6] By no means the least of the bad qualities given to the water by the presence of these bacteria is the offensive and disagreeable taste resulting from the decomposition of the dead organisms.

The city which is unfortunate enough to have a water supply containing iron, and which has endured for a time any or all of its bad qualities, begins either to look for a new and more wholesome and more agreeable supply or to inquire into the steps that are necessary to remove the iron.

It is quite probable that it will be cheaper for the municipality to install an iron-removal plant rather than to secure a new supply. In many cases all ground water, to which the municipality would have access, would come from the same geological formation and consequently would contain iron. If a surface water were secured, the supply would have to be filtered before it would be safe for the use of the city. A purified ground water has the following advantages over a filtered water:[7]

1. Absence of color, odor and objectionable taste.
2. Safety.
3. Small seasonal variation in temperature.
4. Lower cost.
5. Less danger from frost.

THE CHEMISTRY OF IRON REMOVAL.

Iron is very widely distributed, forming about 4.4 per cent of the earth's crust.[8] Practically all of the sands, gravels, soils and rocks with which the water comes in contact contain appreciable amounts of iron salts. If the conditions are typical the water dissolves more or less iron.[9]

Iron exists in water in a form that is slightly soluble, and in this state it is said to be in the ferrous condition. All waters containing iron are similar, in that they contain large amounts of dissolved carbon dioxide or carbonic acid, and little or no dissolved oxygen. On coming in contact with the air the water

6. D. Vollmar, J. Gasbel, 57-945.

7. Weston, R. S., T. A. S. C. E. (1909), 115.

8. Clarke, Data of Geochemistry, 33.

9. Hazen, Clean Water and How to Get It, 52.

loses a good share of the dissolved carbon dioxide and takes up oxygen. This dissolved oxygen changes the iron from the ferrous, or unoxidized condition, to the ferric, or oxidized condition. While the iron is slightly soluble in the water as a ferrous salt—for instance, as ferrous hydroxide—it is no longer soluble after it has been changed by the action of the oxygen of the air to the ferric state. As ferric hydroxide it is precipitated from the solution, giving the water its characteristic bad qualities. Ferric hydroxide is familiar to every one as iron "rust."

The complete change from the ferrous dissolved iron (or clear water) to the water freed from iron in solution, but containing the very finely divided ferric hydroxide (rust) in suspension, has been divided into four steps:[10]

1. The presence of oxygen of the air, by which oxidation is effected.

2. The oxidation of ferrous hydroxide depends upon the decomposition of water (hydrolysis), as expressed in the following equation:

$$\underset{\text{ferrous hydroxide.}}{4Fe(OH)_2} + \underset{\text{water.}}{4(HOH)} + \underset{\text{oxygen.}}{O_2} = \underset{\text{ferric hydroxide.}}{4Fe(OH)_3} + \underset{\text{water.}}{2H_2O}$$

3. The ferrous hydroxide becomes oxidized to ferric hydroxide and exists in the form of a colloidal suspension, until finally—

4. The transformation of the colloidal suspension to the insoluble precipitate is brought about by conditions that influence the precipitation of ferric hydroxide (rust).

In the third step the ferric hydroxide is said to exist in the colloidal state. Colloidal ferric hyroxide may be regarded as rust divided into such small particles that it will pass through all ordinary filtering mediums, but is held back by certain special mediums, such as, for example, parchment. While colloidal ferric hydroxide gives the water an opalescent (roily) appearance, it is so finely divided that the separate particles can not be seen by the aid of the ordinary microscope, though they may be distinguished by the aid of the ultra miscroscope or by the Tyndall meter.[11]

The majority of waters containing iron in solution are of such a character that there is no difficulty in bringing about precipitation. The oxygen is furnished to the water by some method of aëration, and the precipitation of ferric hydroxide begins immediately. However, there are a few exceptions to this ideal condition. Some substances, which may be present in the water, are known to retard the precipitation, or even to hold the ferric hydroxide in

10. Schmidt & Bunte, J. Gasbel, 46, 481. Zft. f. Angew. Chem., 16, 923.

11. Mecklenburg, A., Z. Instrumentenk, 34, 209.

the colloidal state indefinitely. From their action, on aëration, iron-bearing waters may be classified as follows:

CLASS I. In which the ferric hydroxide coagulates and begins to precipitate immediately after aëration.

CLASS II. In which a part of the ferric hydroxide precipitates on aëration and a part is held in the colloidal state indefinitely.

CLASS III. In which all of the ferric hydroxide remains in the colloidal state for an indefinite time after aëration.

Waters of the first class are easily purified by aëration, sedimentation (if necessary), and filtration through some medium, usually sand or gravel.

Waters of the second and third classes require different treatment. Substances which interfere with the precipitation of the ferric hydroxide must be eliminated or their action neutralized in some way. The most common interfering substances are carbon dioxide, organic matter and manganese.[12] Since all acids interfere with the coagulation of colloids, it is to be expected that carbon dioxide (carbonic acid) will retard the precipitation. Fortunately, it is a very easy matter to get rid of this substance, for any aëration that is necessary for the oxidation of the iron will at the same time eliminate a large part of the carbon dioxide.

Some form of the riesler, or trickler, is the most convenient means that has been found for treating a water that contains interfering organic matter. The water is allowed to trickle through a layer of coke, broken stones, or other similar material. The contact with these rough bodies has the power of accelerating the coagulation of the newly formed colloidal ferric hydroxide, so that in many cases a large percentage is precipitated in the riesler and remains as a rusty slime on the surface of the contact material. In addition to this catalytic action, the riesler serves as a means of completely aërating the water, by exposing it in thin films to the action of the oxygen of the air.

The depth of coke, or other similar material, through which the water is allowed to trickle, varies with the time of contact that is necessary to complete the reaction. In some cases results are obtained by limited aëration and a period of submerged contact with the rough material. This submerged contact is sometimes called "scrubbing." The conditions that will give the best results must be determined experimentally for each water. It has been noticed that the action is hastened as the coke or other scrubbing material "ages"; that is, as the amount of ferric hydroxide

12. Weston, R. S., J. N. E. W. W. A., 28 (1914), 28.

deposited increases. From the riesler, after varying periods of sedimentation, the water is led to the filters.

In most waters, this contact with coke or other similar material has been found to precipitate manganese along with the iron. Weston says: "Manganese possesses the power of preventing the removal of the last traces of the iron unless it itself be removed at the same time."[13] However, in our experiments with the Lawrence city water we had no trouble in completely removing the iron, but were unable to remove the manganese by aëration or by any variation of the contact process.

The rates of filtration may be very high. Rapid filters give good results. The precipitated ferric hydroxide forms an excellent floc. The size of the sand or the depth of the filter bed seems to have very little to do with the removal of the iron.

HISTORY.

It has been known for many centuries that iron could be removed from water by allowing the water to stand for some time in contact with the air. The development of the quick processes for the removal of iron from water have been undertaken only within the last fifty years.

The first iron-removal plant was built at Halle, in Germany, in 1868.[14] The water was aërated by allowing it to trickle over coarse gravel, and this was followed by filtration through sand. Little notice was taken of this process, and no other efforts were made to remove the iron from the water supply until 1880, when a plant was built at Tegel,[14] a part of the Berlin water supply. Aëration was furnished by a series of wooden steps, over which the water flowed in a sort of cascade onto the filter. From 1886 until 1892 experiments were conducted on the Berlin ground water. The iron was removed by spraying on gravel or coke tricklers (rieslers), with subsequent filtration through coarse sand, or gravel. Since that time other materials have been used successfully for obtaining the contact action most commonly furnished by coke. Almost any insoluble material that has a rough or porous surface may be used.

Pressure filters were first used for iron removal in the United States. Between 1890 and 1896 several of these were installed in New Jersey. No means of aëration was provided for, and none took place other than that obtained from leaky valves. In 1895

13. Weston, R. S., J. N. E. W. W. A., 28 (1914), 30.

14. Weston, R. S., T. A. S. C. E. (1909), 152.

it was determined, in a series of experiments at Asbury Park, New Jersey,[15] that some form of aëration was necessary before a complete removal of the iron could be effected. Sand was used for the filtering medium. In some cases the water, after being filtered through sand, was again filtered through charcoal.

An artificial zeolite, known as permutite, is being used in Germany[16] to remove iron. It is more generally used as an agent for softening water, and has the composition represented by the chemical formula $n\ SiO^2 \cdot Al^2O^3 \cdot Na^2O \cdot m\ H^2O$, and by passing water through a filter composed of this material the sodium is replaced by many other substances, among which is manganese. If this manganese permutite is treated with a dilute solution of potassium permanganate, the manganese is precipitated throughout the porous material as one of the higher oxides. The manufacturers of this substance claim that this oxide gives up its oxygen so readily that the iron contained in a water coming in contact with it is rapidly oxidized and precipitated.

Most of the installations for removing iron from water that are used in the United States are of the type originated by Oesten, and consist of some method of aëration followed by filtration. However, within the last few years, experiments have been carried out by Mr. R. S. Weston on several New England water supplies, in which the contact action of coke has been made use of.[17] As a result of one of these experiments, a purification plant was built at Middleboro, Mass., in which the iron is precipitated from the water by means of a coke riesler. It has also been shown by the experiments of Mr. F. A. Barbour at Lowell, Mass., that in some cases submerged contact with coke is the only method that will bring about complete precipitation of the iron.[18]

GERMAN PRACTICE.

A large number of German cities depend upon ground water, which contains iron, for their water supply. Necessity has forced them to become pioneers in deferrization processes, and as a consequence they have originated and perfected most of the methods of iron removal now in use. Since different waters require different treatment, depending upon the amount and chemi-

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15. Weston, R. S., loc. cit.

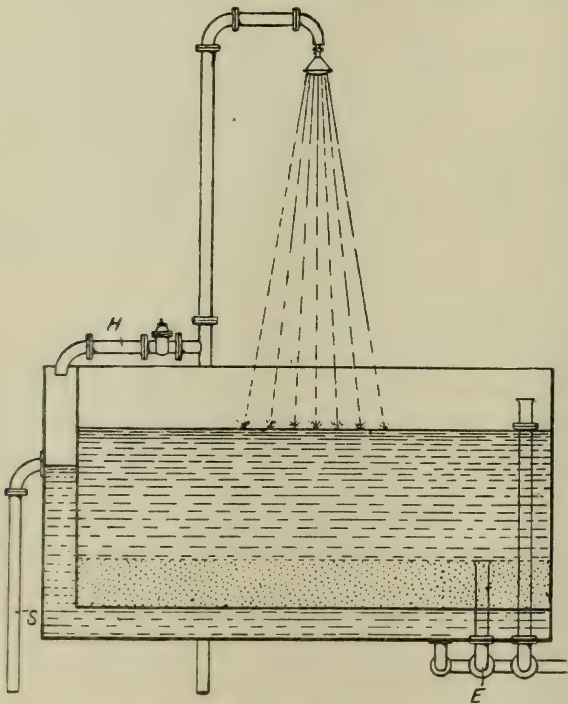
16. Seidler, P., Zft. Angew. Chem., 22, 1019. Hencke, J. Gasbel, 56-234. Duggan, F. P. Paper, June 5, 1912.

17. Weston, R. S., J. N. E. W. W. A., 28 (1914), 27-59.

18. Barbour, F. A., Report on the Improvement of the Water Supply of Lowell, Mass. (1914).

cal combination of the iron they contain, several "systems" of iron removal have been developed.

The simplest of these processes was introduced by G. Oesten.[19] The water is aërated by sprinkling from a height of several feet, and after a period of coagulation is filtered through gravel or coarse sand. The aëration furnished by this method is complete, the water being practically saturated with oxygen when sprinkled



Oesten's method of iron removal.

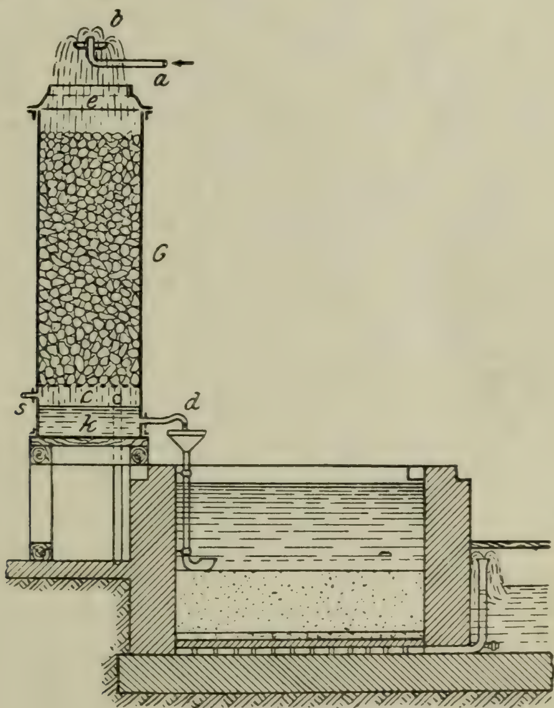
from a height of six to eight feet. The oxygen dissolved by sprinkling from various heights has been determined experimentally by Oesten:

Fall in inches.	O_2 dissolved, in p. p. m.
0 (raw water)	3.15
3.9	4.35
9.8	4.90
19.7	5.60
39.4	8.50
78.8	0

In its original and simplest form, Oesten's apparatus consisted of a sprinkler and a filter. The water is sprinkled directly onto

19. J. Gasbel (1902), 283.

the filter. The sprinkling device is placed at such a height above the filter that enough oxygen is dissolved by the water in falling to oxidize the iron. The filter is of gravel and is about twelve inches in depth. This system of iron removal is used at Freinwalde.[20] The water falls from eighteen sprinklers directly onto the filter. It is thoroughly aërated by its fall and by the spray produced when it rebounds from the surface of the water in the filter. After passing through twelve inches of gravel at a rate of 25 million gallons per acre per day the water is free from iron.



Piefke's method of iron removal.

The latest example of this method of iron removal is found at Potsdam.[21] Aëration is furnished by sprays, but instead of allowing the water to fall from sprinklers it is forced through nozzles, rising to a height of five feet in the form of a fine spray. Two hundred and forty of these nozzles are spaced equally distant from each other in an area thirty-six feet wide and ninety feet long. The aërated water is led into baffled settling basins under

20. Fischer, Das Wasser, Leipsig (1914).

21. J. Gasbel (1914), 886.

the aëration chamber. A minimum period of two hours is allowed to complete the reaction and to furnish time for partial sedimentation before filtering. The filters are of the rapid type and are operated at a rate of 125 million gallons per acre per day. The filtering medium is of finely crushed quartz, with grains 0.75 to 1 mm. in diameter and having a depth of 2.3 feet. As is usual in German practice, the whole plant is enclosed in suitable buildings. Special ventilators supply fresh air to the aëration room, with no danger of contamination from dust or dirt.

Those waters which require a period of contact with some rough material in order to accelerate the precipitation of the iron are, in many cases, allowed to trickle over coke. This method was first used by Piefke.[22] The simplest form of his apparatus is shown in the sketch. The water is evenly distributed over the surface of the coke by means of sprinklers. It trickles through a column of coke from six feet to ten feet deep, dissolving large quantities of oxygen. In this way the iron is rapidly oxidized and precipitated, and a large part of it is deposited on the surface of the coke. This system of iron removal is used at the Elze[23] works of the Hanover city supply to remove 2.6 p. p. m. of iron from ground water. The water is colorless when first pumped from the wells, but it soon becomes turbid, showing all of the characteristics of iron-bearing water. After trickling through coke and filtering through gravel it is odorless and tasteless and contains only 0.05 p. p. m. of iron.

The new installation at Kiel[24] is a good example of Piefke's method. The water, obtained from driven wells, contains 3 p.p.m. iron, is colored with humus compounds and smells strongly of hydrogen sulphide. It is pumped from the wells to a series of troughs and gutters, from which it falls on sheets of perforated corrugated iron and is evenly spread over the surface of coke in the rieslers. After trickling through ten feet of coke it falls into a settling basin underneath the riesler, where a sedimentation period of about one hour is allowed before filtering. The water as it goes to the filters has in suspension as ferric hydroxide only about one-fourth the iron dissolved in the raw water. The filtered water is colorless, odorless, and entirely free from iron.

Although coke is largely used for contact, other materials

22. Zft. Angew. Chem. (1890), 712; (1891), 250.

23. J. Gasbel (1912), 578.

24. J. Gasbel (1911), 271.

have been tried with good results. At Halle,[25] the water falls in thin streams on brick spaced one-half inch apart in a riesler about eleven feet in height. The thorough aëration and contact action obtained by passing through this riesler precipitates all of the iron.

Wellman makes the claim that at Charlottenburg,[26] where coke has been used in several of the rieslers, stone has given much better results. After the stone aged and became covered with ferric hydroxide, its action was almost 50 per cent faster than that of the coke. As the water is run over the coke at the rate of 125 million gallons per acre per day, the rate used in the stone riesler would seem to be too rapid for very efficient action, yet after filtering through sand at the rate of 25 million gallons per acre per day the water is free from iron.

One of the cheapest methods of iron removal is the pressure filter. With certain waters this method of filtration gives good results. Aëration is obtained either by air lift pumps or by the admission of air into the suction line. The various types of filters differ mainly in the filtering medium used. First wooden shavings impregnated with tin oxide were tried, with the idea that the oxide assisted in the oxidation of the iron. Later plain shavings were used with equally good results. The great drawback in the use of shavings is that they soon become foul and require frequent sterilization. Sand has given good results and forms a more satisfactory filtering medium.

Pressure filters are used satisfactorily at Hamburg,[27] where the water contains 0.98 per cent of iron and 0.65 per cent of manganese. The filter removes from 50 to 70 per cent of the iron. This method of treatment is made use of in those cases in which the iron precipitates readily after partial aëration. It can be used with good results with waters of this class, containing only small quantities of iron.

In certain cases in which the iron is in organic combination the addition of chemicals is the most economical method of removal. This is the case at Falkstein.[27] The water contains iron and manganese in combination with humic acids, is highly colored, and though it contains only small quantities of free carbon dioxide, it is quite corrosive. Coagulants are added, and after a period of sedimentation, the water is filtered. At first, lime and sulphate

25. J. Gasbel (1899), 633.

26. J. Gasbel (1894), 595; (1902), 83. Eng. News, 34-147.

27. Herzner, J. Gasbel, 57, 796-798.

of aluminum were added and gave satisfactory results; at the present time, soda solution is used in place of lime water. The filtered water is colorless, is not corrosive and contains but traces of iron.

Since 1900 permutite has been used to remove iron and manganese, and the water furnished to many German cities is purified by this method. The permutite installation at Wilhelmsburg[28] is typical. Small amounts of hydrogen sulphide and iron are removed. Potassium permanganate is added to the raw water to oxidize any of the oxides of manganese (precipitated throughout the permutite) which may have been reduced by the oxidation of the iron. After this treatment, the water is free from iron and hydrogen sulphide.

AMERICAN PRACTICE.

While the number of iron-removal plants in the United States is small, the character of the water from which the iron is removed varies so widely that almost every method of iron removal may be found in practical operation.

The first deferrization plant in this country was built in 1890, at Asbury Park, N. J.[29] The water was pumped directly from the wells to the filters,[30] and the removal of iron was not complete because of a lack of sufficient aëration. At the present time[31] this water is given partial aëration by being pumped into an open tank, and after an hour's sedimentation it is forced through a pressure filter. This filter consists of two tanks, one containing 6 inches of gravel and 2½ feet of sand; the other, 3 feet of bone-black. The water passes through the sand filter first and then through the charcoal. The filter is operated at a rate of five gallons per square foot of filtering surface per minute. The raw water contains 1.1 p. p. m. iron, 97 per cent of which is removed by this treatment. A similar plant is in operation at Atlantic Highlands, N. J.[32]

An iron-removal plant has been in operation at Far Rockaway, N. Y., since 1896.[33] The water, which contains about 2.4 p. p. m.

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28. J. Gasbel. 56, 234-235.

29. Weston, R. S., T. A. S. C. E. (1909), 154.

30. Eng. Rec., 40 (1899), 412.

31. Communication from Superintendent Water and Sewers, Asbury Park, N. J.

32. Weston, R. S., loc. cit. 154.

33. Eng. News, 43 (1900), 238.

iron, is partially aërated and then filtered. The method of aëration is simple. The pipe through which the raw water is brought to the filters stands vertically, with the open end several feet above the water. Sufficient oxygen is furnished to the water as it falls over the edge and down the sides of the pipe to the filter. Slow sand filters are used, and the iron removal is complete.

The water supply of the city of Urbana, Ill.,[34] contains about 2 p. p. m. of iron. Before the completion of an iron removal plant, in 1913, the water furnished was of a very poor quality, due mainly to growths of *Crenothrix* in the distribution system. At present the water supplied to the city is entirely satisfactory, the *Crenothrix* having disappeared from the mains. The water is pumped from the wells to a raw-water reservoir, where some aëration is obtained as it is discharged into the reservoir. From this reservoir the water is pumped to the filters. It is discharged into the filter through an orifice at the end of a vertical pipe, rising as a jet and dropping vertically to the surface of the water in the filter. As a result of this added aëration, the water is practically saturated with oxygen when it reaches the filter. No coagulants are added, since the precipitate of ferric hydroxide gives sufficient "floc" for the operation of the rapid sand filter. By this treatment 85 to 90 per cent of the iron is removed.

At Superior, Wis., water containing about 1.5 p. p. m. of iron is taken from wells sunk forty feet in the sand on the shores of the lake. Before the water was purified it supported growths of *Crenothrix* and ferric hydroxide precipitated in the mains.[35] The original installation (1899) consisted of an aërator of the tray type, and a sand filter. The aërator was made up of two tiers of four trays each, the trays being spaced two feet apart. The bottom tray was made of a steel plate ¼ inch thick, punched with ¼-inch holes. The water was delivered to the top trays and fell over the edge of these trays onto the ones immediately below them, and so on down, finally streaming through the perforated bottoms of the lower trays. This aërator was very efficient. It left the water saturated with oxygen and practically free from carbon dioxide. The aërated water was filtered at a high rate (ten to fifteen million gallons per acre per day) through slow sand filters. The treatment gave only fairly good results. The water no longer supported *Crenothrix*, and very little iron precipitated in the mains; but it had a pronounced color, and analyses

34. Talbot, A. N., Ill. Water Supply Assn. (1914), 149.

35. Eng. News, 45 (1901), 141.

showed almost 1 p. p. m. iron. In 1906 experiments were carried out by W. C. Lounsberry[36] which showed that if the water were carried directly onto the filters, with no aëration aside from that due to leaky valves, the removal of iron was much more complete and the color was almost absent in the filtered water. Since that time the water has been filtered without aëration, and is entirely satisfactory. In this case carbon dioxide and a very slight excess of dissolved oxygen are necessary to obtain results. The color is due probably to some obscure combination of iron which forms readily in the presence of oxygen if carbon dioxide is absent, or present only in very small amounts. Iron-removal plants using the same method that was first tried at Superior, Wis., are in operation at Red Bank, N. J.; Richmond, Mo.; Garrettsville, Ohio; Shelby, Ohio; and North Kansas City, Mo. A similar plant at Excelsior Springs, Mo., is in process of construction, and plans for another have been submitted to the city of Manhattan, Kan.

These plants differ chiefly in the construction of the aërator. At Red Bank, N. J.,[37] the pipe carrying the water to the filters stands vertically several feet above the water level, and the end of this pipe is closed. The sides are perforated with ¼-inch holes, the water being forced from these holes in jets, giving sufficient aëration.

The tray type of aërator is used at Richmond, Mo.[38] Four trays, each 2 feet by 6 feet by 6 feet deep, are superimposed so that there is a vertical distance of 2 feet between each tray. The bottoms of the trays are made of wire net, and support a galvanized-iron plate punched with ⅛-inch holes spaced ½ inch apart. The water is delivered to the top tray and falls in thin streams through it and the lower trays. A similar aërator is in operation at Liberty, Mo.[38]

Aëration is furnished at Garrettsville, Ohio,[39] where the water at the point of discharge into the settling basin falls from a vertical pipe over the edge of the pipe and down its sides onto an umbrella-shaped device 4 feet in diameter. The water falls 5 feet from the edges of the "umbrella" to the surface of the water in the settling basin.

The plans for the plant at Excelsior Springs,[40] Mo., call for an

36. Lounsberry, Wm. C., Proc. Am. W. W. Assoc. (1909).

37. Weston, R. S., T. A. S. C. E. (1909), 126.

38. Hubbard & Kiersted, Water Works Management and Maintenance (1907).

39. T. A. S. C. E. (1909).

40. Communication from M. T. Veatch, of Worley & Black Eng. Co., Kansas City, Mo.

aërator of the tray type. It differs from the one at Richmond, Mo., in that the water, instead of streaming through the perforated bottoms of the trays, falls in thin sheets from the edge of one tray to the tray below it.

In some cases the iron content of a water is of great assistance in the removal of color. This is the case at Miraflores,[41] in the Panama Canal Zone. The supply is taken from Miraflores lake. The raw water contains 0.8 to 2.5 p. p. m. iron, is colored, and has an objectionable odor, due to the hydrogen sulphide gas formed by the decaying vegetable matter present. Very thorough aëration is necessary in order to eliminate the odors, and this treatment precipitates the iron. The coagulation of the ferric hydroxide helps in removing the color by reducing the amount of sulphate of aluminum which must be added to effect a complete removal. This assistance is vital in waters of low alkalinity and high color. The aëration is furnished by means of sprays. One hundred and five specially designed nozzles are spaced equally distant over an aëration basin 86 by 125 feet in area. Water is forced from these nozzles with sufficient pressure to cause it to rise to a height of 15 to 20 feet in the form of a very fine spray. After aëration the water is led into a baffled sedimentation basin, sulphate of alumina is added, and the water is passed through rapid sand filters.

In all of these cities, with the exception of Superior, Wis., no difficulty was experienced in causing the ferric hydroxide to precipitate when sufficient time was allowed for coagulation after aëration. This is not always the case. There are several water supplies in the United States which contain iron in such amounts that purification is necessary and in which iron will not coagulate after aëration. At the present time there are two methods of removal which have been successful in the treatment of such waters: lime and sulphate of aluminum may be added, or in most cases the coagulation may be brought about by a suitable period of contact with some rough material such as coke.

The city of Reading, Mass., is furnished with water originally containing about 9 p. p. m. iron,[42] and which is secured from filter galleries placed in the water-bearing gravel in the banks of the Ipswich river.[43] It contains also varying amounts of humus substances with which iron will combine under certain conditions, and this combination is not broken up by aëration, as it is formed

41. Wells, G. M., J. N. E. W. W. A., 28, 238-267.

42. Weston, R. S., T. A. S. C. E. (1909), 126.

43. Communication, Mr. L. M. Bancroft.

more readily in the absence of carbon dioxide. Since the building of the filter galleries in 1890, various methods of purification have been tried. At the present time lime and sulphate of aluminum are used. The iron content is reduced from 9.4 p. p. m. to 0.05 p. p. m. by the addition of 0.9 pound of lime per 1000 gallons and 2 to 2½ grains of sulphate of aluminum per gallon, followed by rapid filtration.

The water supply for the city of Colon,[44] Panama, contains about 2 to 3 p. p. m. iron. The iron is held in suspension by the organic matter present in the water. Before the method now in use was adopted, this suspension of ferric hydroxide would rapidly clog the filters. To remedy this situation a coagulation basin was built, and the water was treated with 1 to 1.5 grains of aluminum sulphate per gallon. A great part of the aluminum hydroxide precipitate settles out, taking the iron with it. The work of the filters has been much more satisfactory, and the effluent is colorless and free from iron.

In many cases the action of those substances which interfere with the precipitation of iron from water may be neutralized by contact with a rough, porous material. This method of bringing about coagulation of the ferric hydroxide is the latest of the several methods of iron removal to be used in the United States.

In June, 1914, Mr. R. S. Weston[45] published experimental results showing the action of contact with coke in removing iron from water in which organic matter and manganese acted as interfering substances. Results were given on waters from three New England cities, and in each case the iron was held in colloidal suspension by different substances. At Cohasset, Mass., organic matter kept the iron from coagulating after oxidation. Limited aëration, followed by a short period of submerged contact with coke, was shown experimentally to be the necessary treatment, and the period of submerged contact with coke varied with the season of the year. The effluent was filtered through sand.

At Brookline, Mass., both organic matter and manganese interfere with the precipitation of ferric hydroxide. In this case a satisfactory removal was effected by allowing the water to trickle through ten feet of coarse coke at a rate of 75 million gallons per acre per day, followed by filtration through sand at the rate of 10 million gallons per acre per day.

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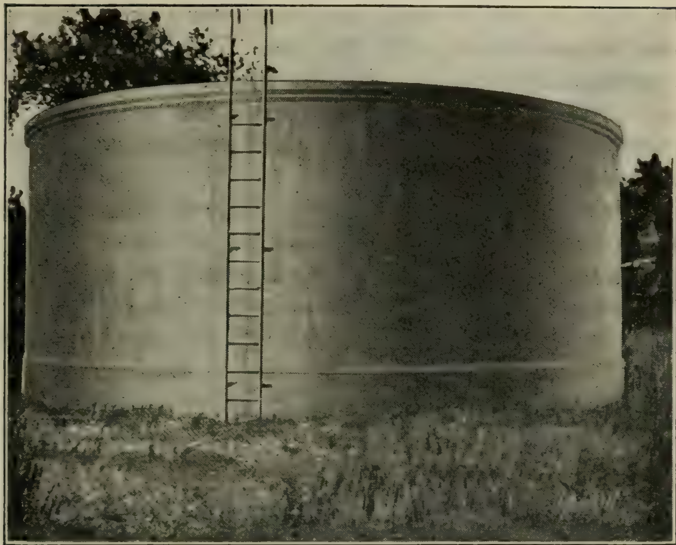
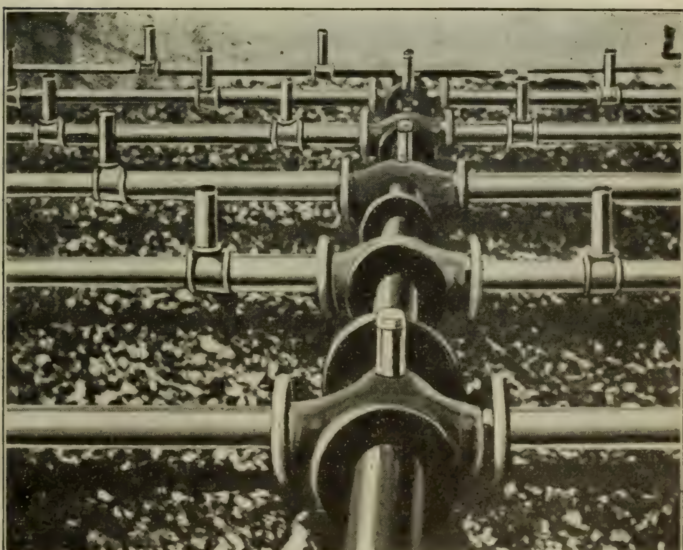
44. Downes, John R., Proc. Am. W. W. Assn. (1910), 220.

45. Weston, R. S., J. N. E. W. W. A. (1914), 27-59.



Riesler, Middeboro, Mass.



Middeboro, Mass., piping for spreading raw water evenly on coke in the riesler.

Manganese interfered at Middleboro, Mass. Satisfactory iron removal was impossible until conditions were such that manganese was removed along with the iron. This was brought about by completely aërating the water by trickling it through ten feet of coke. After a period of sedimentation the water was filtered. As a result of these experiments, a plant was installed for treating the entire supply.

An experimental plant was set up at Lowell, Mass., in 1913, to determine the most satisfactory method of removing iron and manganese from the city water. As the result of a long series of experiments, it was found that a satisfactory removal was brought about by limited aëration, followed by submerged contact with coke. The coke prefilter was eight feet in depth and the water was applied at a rate of 67.5 million gallons per acre per day. The effluent from the prefilter was filtered through a sand filter at a rate of 10 million gallons per acre per day.

IRON IN KANSAS GROUND WATERS.

The following list gives the iron content of the water supplies of Kansas. The analyses were made partly in this Division and partly in the laboratories of the State Water Survey. In these analyses the iron and aluminum were determined together as iron oxide and aluminum oxide. The iron values, as listed below, were computed from the mixed oxides, assuming that there was no aluminum oxide present. In most instances the value given is the average of two or more determinations made at yearly intervals.

IRON CONTENT OF KANSAS GROUND-WATER SUPPLIES.

TOWN.	Iron, p. p. m.	Source of supply.
Abilene	0.50	Springs collected in well.
Almena	7.00	Wells, 55 feet deep.
Altoona	——	Shallow wells, Verdegris river, not used for drinking water, 33 feet deep.
Anthony	3.10	Shallow wells.
Arkansas City	0.04	Shallow wells, 42 feet deep, Arkansas river underflow.
Ashland	——	Shallow wells.
Atwood	0.90	Wells, 32 feet deep.
Baldwin	0.90	Infiltration gallery, 12 to 18 feet deep.
Baxter Springs	0.90	Well, 1100 feet deep.
Belle Plaine	3.30	Shallow wells, 41 feet deep.
Belleville	30.00	Dug wells, 190 feet deep.
Beloit	0.90	Shallow wells, 44 feet deep.
Bennington	1.40	Shallow wells, 50 feet deep.
Blue Rapids	1.40	Shallow wells, 30 feet deep.
Bonner Springs	0.90	Shallow wells, 37 feet deep.
Bucklin	0.29	Dug well, 104 feet deep.
Bunkerhill	1.90	Springs.
Burden	0.70	Springs.
Burr Oak	0.70	Shallow well, 60 feet deep.
Caldwell	——	Well, 50 feet deep.
Cawker City	0.96	Shallow wells, 60 feet deep.
Chapman	——	Shallow wells, 68 feet deep.
Cherokee	0.70	Deep well, 915 feet deep.
Cimarron	0.48	Shallow well, 160 feet deep.
Clay Center	3.20	Shallow wells, 35 feet deep.
Chetopa	1.30	Well, 1102 feet deep.
Clearwater	2.00	Shallow wells, 50 feet deep.
Clifton	1.30	Shallow wells, 65 feet deep.
Clyde	1.50	Shallow wells.
Colby	1.60	Well, 140 feet deep.
Coldwater	0.04	Shallow well, 70 feet deep.
Columbus	0.60	Deep well, 1200 feet.
Concordia	0.12	Shallow well, 48 feet deep.
Conway Springs	0.60	Well, 40 feet deep.
Delphos	1.30	Shallow wells.
Dodge City	1.50	Shallow wells, 25 feet deep.
Downs	0.80	Shallow wells, 60 feet deep.
El Dorado	0.60	Wells, 21 to 30 feet deep, in filtration galleries.
Ellinwood	0.40	Shallow wells, 145 feet deep.
Ellis	0.82	Wells.
Ellsworth	0.50	Wells, 26 to 35 feet deep.
Englewood	1.80	Well.
Enterprise	1.20	Well, 43 feet deep.
Erie	0.70	Well, 40 feet deep.
Esbon	2.40	————
Eureka	3.40	Well, 21 feet deep.
Florence	1.90	Well.
Fowler	0.07	Well.
Frankfort	——	Well, 105 feet deep.
Frontenac	0.96	Deep well, 1040 feet deep.
Garden City	1.10	Wells, 20 to 45 feet deep.
Girard	0.80	Deep well, 1146 feet deep.
Glasco	1.10	Plant built, 42 feet deep.

IRON CONTENT OF KANSAS GROUND-WATER SUPPLIES—CONTINUED.

Town.	Iron, p. p. m.	Source of supply.
Glen Elder	——	Well.
Goodland	Tr.	Well.
Great Bend	——	Wells, 70 to 80 feet deep.
Green	0.60	Wells, 862 feet deep.
Greenleaf	1.50	Wells, 100 feet deep.
Halstead	1.90	Wells, 100 feet deep.
Hanover	1.70	Wells, 46 feet deep.
Harper	None.	Wells, 40 feet deep.
Hays	2.00	Wells.
Havensville	0.80	Wells, 25 feet deep.
Herington	0.90	Wells, 160 feet deep.
Hiawatha	Tr.	Wells, 25 to 31 feet deep.
Highland	0.50	Wells, 52 feet deep.
Hill City	1.30	Wells, 28 feet deep.
Hoisington	0.68	Wells, 55 feet deep.
Holton	——	————
Holyrood	3.70	Wells, 120 feet deep.
Humboldt	0.65	Wells, 30 feet deep.
Hutchinson	1.20	Wells, 60 to 85 feet deep.
Jamestown	1.30	Wells.
Jetmore	——	————
Junction City	1.20	Wells.
Kensington	1.60	Wells.
Kingman	2.60	Springs.
Kinsley	1.10	Wells.
Kiowa	1.10	Wells.
Kirwin	——	————
Kanopolis	1.50	Wells, 40 feet deep.
La Cygne	0.90	Wells, 40 feet deep.
Larned	2.10	Wells, 20 to 105 feet deep.
La Harpe	Tr.	————
Lawrence	14.00	Shallow wells, 35 feet deep.
Lebanon	0.75	Springs.
Liberal	Tr.	Wells.
Lincoln	0.80	Wells, 50 to 60 feet deep.
Little River	25.00	Well.
Lindsborg	0.70	Well, 85 feet deep.
Logan	0.10	Well, 20 feet deep.
Lucas	1.80	Well.
Luray	2.00	Well.
Lyons	0.50	Wells, 60 feet deep.
McPherson	2.50	Wells, 140 feet deep.
Madison	0.90	Wells.
Manhattan	4.70	Wells, 40 feet deep.
Mankato	1.30	————
Marquette	0.09	Well.
Meade	1.80	Wells, 176 to 293 feet deep.
Miltonvale	4.90	Well.
Mineral	0.50	Deep well.
Minneapolis	1.60	Well.
Moline	——	Well, 34 feet deep.
Moundridge	0.80	Wells, 20 to 200 feet deep.
Mulberry	0.50	Deep well, 1000 feet deep.
Mulvane	2.00	Wells, 30 feet deep.
Newton	1.90	Wells, 120 to 130 feet deep.
Norton	2.40	Wells, 35 to 60 feet deep.

IRON CONTENT OF KANSAS GROUND-WATER SUPPLIES—CONCLUDED.

TOWN.	Iron, p. p. m.	Source of supply.
Nickerson	——	————
Oakley	4.10	Wells.
Oberlin	2.30	Wells.
Onaga	9.40	Wells.
Osborne	1.50	Well, 50 feet deep.
Oxford	0.68	Wells, 38 feet deep.
Peabody	0.88	Wells, 27 to 30 feet deep.
Phillipsburg	3.20	Wells.
Pittsburg	0.07	Deep wells, 1300 to 1500 feet deep.
Plainville	1.10	Wells.
Pratt	0.90	Wells, 50 to 65 feet deep.
Sabetha	1.20	Wells.
St. John	0.90	Wells, 50 feet deep.
St. Marys	0.60	Wells.
Salina	0.97	Wells.
Scammon	0.96	Deep wells, 800 feet deep.
Scandia	1.60	Wells, 25 feet deep.
Scott City	1.60	Wells, 82 feet deep.
Sedgwick	4.40	Wells.
Seneca	0.82	Wells, 60 feet deep.
Sharon Springs	0.27	Wells.
Smith Center	3.40	Wells and infiltration gallery.
Stafford	0.90	Wells.
Sterling	0.40	Wells, 30 feet deep.
Stockton	1.40	Well, 32 feet deep.
Strong City	3.70	————
Sylvan Grove	1.30	Wells, 58 feet deep.
Syracuse	0.55	Well, 482 feet deep.
St. Francis	1.60	————
Topeka	2.50	Wells, 45 feet deep.
Turon	1.30	Well.
Udall	1.60	————
Valley Falls	0.00	Springs.
Wa Keeney	1.40	Well, 34 feet deep.
Wakefield	1.10	Wells, 54 feet deep.
Wamego	2.00	Wells, 60 feet deep.
Waldo	——	————
Waterville	1.00	Wells, 64 feet deep.
Waverly	1.80	Wells, 20 to 25 feet deep.
Weir City	0.80	Wells.
Wellington	——	————
Wichita	0.68	Wells, 43 feet deep.
Wilson	0.96	Wells.

MANGANESE.

More than twenty years ago Proskauer reported the presence of manganese in many ground waters. For a long time afterward little attention was given to the subject, for it had not been proved that manganese imparted any bad qualities to water. In 1906 the sudden appearance of large quantities of manganese and iron in the water supply of the city of Breslau[1] forced recognition of the fact that manganese and iron produce like qualities in water.

The ground-water supply of Breslau was obtained from 313 wells, 30 or 40 feet deep, situated in the valley of the Oder river. In 1906 the Oder overflowed its banks. Very soon afterward the manganese and iron increased to 220 p. p. m. and 440 p. p. m., respectively. The conditions resulting from these very large quantities of manganese and iron were such that it is commonly referred to as the "Breslau calamity." The supply was ruined, and had to be abandoned for filtered surface water.

Since that time manganese has given trouble in other cities. Dresden, Nordhausen, Stettin, Bernberg, Krefeld and other German water supplies are equipped with plants for removing manganese.

Many ground waters in the United States contain small quantities of manganese, but thus far these waters have given little trouble. In some cases, however, water pipes have been clogged by deposits of manganese oxides. Such deposits have been reported from Mt. Vernon, Ill.,[2] Hutchinson, Kan.,[3] and Lawrence, Kan.[4]

In many cases these small quantities of manganese have very little effect upon the quality of the water. Yet 0.5 p. p. m. of manganese in solution in water is enough to support the growth of manganese bacteria.[5] These bacteria are a species of *Crenothrix*, which precipitate oxides of manganese in the gelatinous sheath surrounding them. Several different species have been described by Jackson.[6] The most common is known as *Crenothrix manganifera*. These bacteria affect the character of the water in the same way as the iron bacteria, imparting the same disagreeable qualities to it.

1. Luehrig, H., Chem. Ztg., 31-255.
2. Ill. State Water Survey Bull. No. 10, p. 57.
3. Bailey, E. H. S., J. Am. Chem. Soc., 26-714.
4. Young, C. C., Proc. Ill. Water Supply Assn. (1913), 81.
5. Tillmans, J., J. Gasbel, 57 (1914), 713.
6. Jackson, D. D., Trans. Am. Mic. Soc., 23-31. J. Soc. Chem. Ind., 21-681.

In many of its other characteristics a water which contains manganese is very much like a water which contains iron.

For instance, if conditions are favorable, the water, after being in contact with the air for some time, will give up a part of its manganese as a dark-brown or black precipitate. In short, there is little difference between the troubles caused by waters containing iron and those which contain an equal amount of manganese. This similarity is due to the fact that the chemical compounds of manganese and iron have many properties in common. Manganous salts act somewhat similarly to ferrous salts. All are fairly soluble with the exception of the carbonate; ferrous hydroxide is readily oxidized to ferric hydroxide by the action of the oxygen of the air. In a similar manner, if the conditions are favorable, manganous hydroxide is easily oxidized to manganese tetrahydroxide; but manganous salts are much more stable than the corresponding ferrous salts. Iron salts in neutral, acid or basic solutions are hydrolyzed, and are, in the presence of oxygen, precipitated as ferric hydroxide. Manganous salts are not so readily hydrolyzed, and, in the presence of oxygen, precipitate readily in the presence of hydroxyl ions.

Several methods have been used for the removal of manganese from water. Treatment with ozone is the surest means of elimination, but its cost is prohibitive unless the water requires sterilization as well as demanganization.[7]

Most methods for the removal of manganese are very similar to those used for iron removal. Since so many of the chemical properties are similar, it is reasonable to assume that the salts of the two metals can be removed by similar means. In most cases such methods are successful. It has been noticed by many observers, however, that manganese precipitates much more slowly than iron. This is shown when a water contains iron and manganese so combined chemically that both may be removed by aëration and filtration. In such a case it has been observed that the precipitated iron hydroxide is caught and held in the first few inches of the filter sand. Below this iron deposit will be an area free from any metallic oxides, and down deep in the sand will be found a layer of manganese dioxide several inches in thickness.[8]

However, many waters which contain manganese are not affected by aëration and filtration. Contact with coke or some other rough material has been found to bring about the required reaction in certain cases. Sometimes the scrubbing action of

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7. Tillmans, J., J. Fur Gasbel, 57-731.

8. Weston, R. S., T. A. S. C. E. (1909), 173.

submerged contact is necessary. As is the case with some iron waters, the removal of manganese is not complete until the contact material has been in use for some time and has become covered with a layer of the precipitated oxide.

The manufacturers of permutite, a patent material used for manganese removal, make use of this principle.[9] Manganese permutite is formed by treating sodium permutite with a solution of manganous chloride. The manganese is precipitated in the form of higher oxides by the addition of a dilute solution of potassium permanganate. In this way a fine, evenly distributed precipitate of higher oxides of manganese is formed throughout the entire mass, and much the same effect is obtained as in a contact bed covered with oxides deposited from the water.

In each instance in which manganese is removed from a water the rate of precipitation seems to be greatly accelerated by contact with manganese dioxide or with one of the higher oxides of manganese. As has been shown, the oxides of manganese may be a deposit in the filter sand or on the contact material of the riesler formed naturally from the manganese of the water being treated, or, as is the case with permutite, the deposit may have been formed artificially by more rapid chemical means. But in every case in which manganese is removed without the addition of chemicals, contact with the oxides of manganese seem to play an important part in the process.

Reasoning from these observations, Dr. J. Tillmans[10] has advanced the theory that complete and effective manganese removal is obtained only in the presence of manganese dioxide or some of the other higher oxides of manganese. He has carried out a long series of laboratory experiments which seem to confirm his assumptions. Among several possible explanations for this action, he thinks it most probable that manganese dioxide dissolves, forming a solid solution; in contact with oxygen this dissolved manganese hydroxide goes over to manganese dioxide.

The deposit of manganese oxide on the contact material of a riesler is explained as follows: Very small amounts of manganous hydroxide are formed by hydrolysis, as shown in the following equations:

$$\underset{\text{manganese sulphate.}}{MnSO_4} + \underset{\text{water.}}{2H_2O} = \underset{\text{manganous hydroxide.}}{Mn(OH)_2} + \underset{\text{sulphuric acid.}}{H_2SO_4}$$

$$\underset{\text{manganese bicarbonate.}}{Mn(HCO_3)_2} + \underset{\text{water.}}{2H_2O} = \underset{\text{manganous hydroxide.}}{Mn(OH)_2} + \underset{\text{carbon dioxide.}}{2CO_2} + \underset{\text{water.}}{2H_2O}$$

9. Siedler, P., Zft. angew. Chem. 22, 1019.

10. Loc. cit.

These are reversbile reactions. If manganous hydroxide is dissolved by manganese dioxide, the reaction continues and in the presence of excess manganese dioxide is carried on until all of the manganese is removed from the water. The contact material also gives the water a slightly alkaline reaction in the thin film adjacent to each separate piece of material, accelerating the formation of manganous hydroxide.

Thus the action of a riesler would be constantly increasing in efficiency. At first very small amounts of manganous hydroxide would be deposited, and rapidly oxidized to manganese dioxide or other higher oxides. This oxide would dissolve a little more of the manganous hydroxide from the water passing over it, causing a little greater removal of manganese. In this way, more and more of the manganese is precipitated on the contact material, until finally the reaction is complete and all of the manganous hydroxide is precipitated from the water as it trickles over the oxide-covered material.

If these assumptions are true, a very practical difficulty presents itself. Waters which contain manganese frequently contain even larger amounts of iron. The iron will probably precipitate readily, and this precipitation will mechanically inclose each little particle of manganese oxide that may be formed, reducing its effect upon the manganous hydroxide in solution. It is noticeable from what little data is obtainable on manganous removal that, in those cases in which the riesler has been effective in removing manganese, the iron content was not much in excess of the manganese content, so that the precipitated manganese dioxide was directly in contact with the water, giving every opportunity for the formation of a heavy deposit.

Another very interesting form of manganese removal is the so-called biological demanganization of water. Doctor Vollmar, of the Dresden waterworks, has developed this method for removing the manganese from the water he furnishes to that city.[11]

The water as pumped from the wells contained about 1 p. p. m. of manganese, but at all times of the year it supported a luxuriant growth of manganese bacteria. These growths were very troublesome, and in certain seasons they increased to such proportions that the water was unfit for use.

Doctor Vollmar noticed that the *Crenothrix* grew luxuriantly in the wells and reservoirs, and that a good share of the growth in the distribution system was carried into the pipes from the

11. Vollmar, D., J. Gasbel, 57, 944.

reservoirs. Thinking that filtration might be of some value, a small experimental pressure filter was set up. From these experiments it was determined that the water could be freed from manganese by filtering. The demanganization, however, was dependent upon a layer of *Crenothrix* which formed a thick mat on top of the filtering material. After passing through this mat of *Crenothrix*, and on through twenty inches of fine, porous gravel, the water was free from manganese as well as from *Crenothrix*. When too thick a mat of *Crenothrix* had formed on top of the gravel for effective filtering, it was easily washed by reversing the flow of the water.

As a result of these successful experiments, pressure filters were installed and the entire supply subjected to this treatment. The results have been very satisfactory.

Tillmans says that the oxides of manganese deposited in the sheath of the bacteria have the same effect, and no more effect, than any other oxide of manganese with which the water may come in contact. He also states that the deposit of these oxides is started by hydrolysis and adsorption, and is built up in the same manner as the deposit on the rough material in a riesler. The more rapid deposition may be accounted for by the fact that the sheath of the bacteria has an alkaline reaction.

Vollmar believes that the deposit of manganese has a more intimate connection with the life process of the organism, and that the oxygen set free by the bacteria in obtaining carbon from the carbon dioxide plays a necessary part in the reaction.

The experimental work and theories that have been described give us the latest ideas of German engineers. So far very little experimental or research work has been done in this country. Although very many of the water supplies in the United States contain small amounts of manganese, very few cities have taken any steps to remove it.

A series of experiments have shown that 1 p. p. m. of iron and 3 p. p. m. of manganese could be removed from the Boulevard water of the Lowell, Mass., supply.[12] The treatment consists of limited aëration, followed by submerged contact with ten feet of coke at the rate of 67.5 million gallons per acre per day, followed by sand filtration.

The experimental results obtained at Lawrence, which are given in the last section of this paper, show that the manganese content

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12. Barbour, F. A., Report on the Improvement of the Water Supply of Lowell, Mass., 1914.

of the Lawrence supply is not affected by the contact action of the coke trickler. This could be explained by Tillmans' theory, from the fact that the much heavier precipitate of ferric hydoxide would prevent the formation of a deposit of oxides of manganese on the coke, and only the slight amount of manganese hydroxide formed by hydrolysis is removed.

LAWRENCE EXPERIMENTS.

The Lawrence city water supply is secured from wells thirty-five to fifty feet deep, in the Kaw river bottoms. The water is typical of many Kansas waters in that it is quite hard and contains a large amount of iron. As it receives no purification other than limited aëration and sedimentation, the supply is unsatisfactory, possessing, as it does, the bad qualities of an iron water together with those of a hard water.

In order to determine just what treatment is necessary to remove the iron, an experimental plant was built by the Division of State Chemical Research at the city waterworks in July, 1914, and a series of experiments was conducted. The work was carried out with the coöperation of Prof. C. C. Young, director of the state water and sewage laboratories. These experiments were conducted until the latter part of October, 1914, when they were stopped because the high-pressure water lines, from which power was obtained for pumping water from the well and for washing the filter, were dismantled.

The water was taken from a well which is thirty-five feet deep, and which is one of the two wells sunk in the spring of 1914. This water does not differ in quality from that furnished by the other wells, and is typical of the city supply. It has the following analysis:

ANALYSIS. JULY 28, 1914.

Radical.	P. p. m.
SO_4	41.00
HCO_3	476.00
Cl	23.00
Na	12.00
Ca	138.00
Mg	23.00
Al_2O_3FeO	25.20
Fe	17.00
Mn	1.16
SiO_2	32.00

Lawrence experimental plant.

The iron and manganese content varied from day to day. During the dry weather of the summer the iron fell as low as 11 p. p. m., but the manganese was more constant, the minumum being 0.9 p. p. m.

The design of the plant is shown in the sketch. It consists of an aëration tower, a sedimentation basin, and a rapid sand filter.

The aëration tower, or tank, was made of galvanized iron and was three feet in diameter and ten feet in height. The water was led in from the top to a sewage nozzle so placed that it could be raised to any desired height above the bottom of the tank. It was possible to regulate the fineness of the spray from the nozzle by means of a setscrew.

The sedimentation basin consisted of eight fifty-gallon barrels, baffled and connected in series.

The filter was a rectangular tank of galvanized iron, one foot wide, two feet long and ten feet high. This tank was fitted with Wheeler underdrains, a wash-water trough and loss-of-head gauges, forming a very satisfactory filter. Wash water was taken from the city mains, since it was not possible, with the pumping facilities available, to use the filtered water for this purpose.

The sand used in the filter was taken from the well when in the process of construction. Its effective size was 0.35 mm.; its uniformity coefficient, 1.7.

The construction of the plant was completed on July 25, 1914, and its operation was started on the following day.

Experimental.

The purpose of this work was to determine as accurately as possible the conditions under which iron could be most effectively and economically removed from the water, and to determine what effect the methods used for iron removal would have on the manganese content of the water.

EXPERIMENT I.

Purpose.

The purpose of this experiment was to determine the effect upon the iron content of the water of aëration followed by sedimentation and filtration.

Conditions.

The water was sprinkled from the top of the aëration tower, falling in small drops through a distance of eight feet to the bottom

of the tower. A period of one and one-half hours was allowed for coagulation and sedimentation before filtering. The filter was operated at a rate of 125 million gallons per acre per day.

Results.

AVERAGE OF ANALYSES. JULY 28 TO AUGUST 7.

(Results expressed in p. p. m.)

	Raw water.	Aërator effluent.	Filter effluent.
Dissolved oxygen	.30	6.4	.....
Free carbon dioxide	74.00	39.0	29.00
Iron	18.30	....	.04
Manganese	1.15	....	.99

The analyses of the filtered water showed that the iron was removed to a satisfactory degree by aëration, but that only a very slight removal of the manganese was effected.

The period of sedimentation was too short. Much more of the flocculent precipitate of ferric hydroxide was carried onto the filter than was necessary for its operation, and thereby caused a rapid increase in the loss of heat and made frequent washing necessary.

EXPERIMENT II.

Purpose.

The purpose of this experiment was to increase the period of sedimentation to such an extent that the filter could be operated more efficiently.

Conditions.

A much finer spray was used for aëration than in the previous experiment. The drop from the spraying nozzle to the bottom of the tank was left at eight feet. The period of sedimentation was increased to two hours and twenty minutes. The water was filtered at a rate of 125 million gallons per acre per day.

Results.

AVERAGE OF ANALYSES. AUGUST 7 TO 14.

(Results expressed in p. p. m.)

	Raw water.	Aërator effluent.	Filter effluent.
Dissolved oxygen	.07	7.4	....
Free carbon dioxide	78.00	....	9.00
Iron	17.00	....	.02
Manganese	1.10	....	.93

The operation of the filter was much more satisfactory with this period of sedimentation, using wash water equal to 4 per cent

of the filtered water. However, the more complete aëration given the water had no effect upon the iron removal.

EXPERIMENT III.

Purpose.

The purpose of this experiment was to determine whether a shorter period of sedimentation would give satisfactory results.

Conditions.

The period of sedimentation was reduced to two hours. The other conditions were the same as in the preceding experiment, with the exception of the aëration, which was reduced by means of a coarser spray.

Results.

AVERAGE OF ANALYSES. AUGUST 15 TO 16.

(Results expressed in p. p. m.)

	Raw water.	Aërator effluent.	Filter effluent.
Free carbon dioxide	74.00	....	12.00
Oxygen	.09	6.2	.....
Iron	11.00	....	.06

The operation of the filter was satisfactory with this period of sedimentation. Since one and one-half hours sedimentation had proved too short a time, it was concluded that at least two hours were necessary to permit the excess of coagulated ferric hydroxide to settle from the water.

EXPERIMENTS IV, V, VI, VII.

Purpose.

The purpose of these experiments was to see the effect upon the iron content of the filtered water by increasing the rate of filtration from 156 million gallons per acre per day to 250 million gallons per acre per day.

Conditions.

Aëration was furnished as before. A two-hour period of sedimentation was allowed in experiments IV and V; in experiments VI and VII a shorter period was necessary, due to the limited capacity of the settling basin. The filter was operated at the following rates:

Experiment IV	156 million gallons per acre per day.
V	188 million gallons per acre per day.
VI	219 million gallons per acre per day.
VII	250 million gallons per acre per day.

Results.

IV.

AVERAGE OF ANALYSES. AUGUST 17 TO 18.

(Results expressed in p. p. m.)

	Raw water.	Aërator effluent.	Filter effluent.
Dissolved oxygen	.07	6.80	.....
Free carbon dioxide	71.00	....	5.00
Iron	10.90	....	.90
Manganese	1.03	....	.90

V.

ANALYSIS. AUGUST 20.

	Raw water.	Aërator effluent.	Filter effluent.
Iron	14.40	....	.....
Manganese	1.20	....	.90

VI.

ANALYSIS. AUGUST 24.

	Raw water.	Aërator effluent.	Filter effluent.
Dissolved oxygen	1.05	6.90	.....
Free carbon dioxide	70.00	....	5.00
Iron	10.40	....	Trace.
Manganese	.96	....	.90

VII.

ANALYSIS. AUGUST 25.

	Raw water.	Aërator effluent.	Filter effluent.
Dissolved oxygen	.75	6.80	.....
Free carbon dioxide	70.00	....	20.00
Iron	13.20	....	None.
Manganese	.98	....	.90

These analyses show that the iron is completely removed from the water when very high rates of filtration are used.

EXPERIMENT VIII.

Purpose.

The purpose of this experiment was to determine the effect upon the iron and manganese content of the water of trickling the water through an eight-foot column of coke.

Conditions.

The aëration tower was filled to a depth of eight feet with coarsely broken coke. An orifice box was installed, so that a constant volume of water could be delivered to the riesler. In this

experiment and in the following, the water was run through the coke at a rate of 71 million gallons per acre per day. A higher rate would have been used if possible, but the water was so low in the wells that this volume was all that the pump could furnish.

A sprinkling device was added, so that the water was evenly distributed over the surface of the coke. Because of this aëration, the water as it reached the surface of the coke was 40 per cent saturated with oxygen.

A period of sedimentation of one and one-half hours was used in this and the following experiments, and was sufficient to give efficient operation of the filter.

The rate of filtration was 125 million gallons per acre per day.

Results.

AVERAGE OF ANALYSES. AUGUST 31 TO SEPTEMBER 3.

(Results expressed in p. p. m.)

	Raw water.	Riesler effluent.	Filter effluent.
Dissolved oxygen	1.27	8.70	.....
Free carbon dioxide	72.00	....	3.00
Iron	11.90	2.30	Trace.
Manganese	.99	.94	.88

The aëration given by this treatment was complete, the effluent from the riesler being saturated with oxygen and nearly free from carbon dioxide. The contact with the coke accelerated the coagulation of the ferric hydroxide, so that 75 to 80 per cent of the precipitate was left on the surface of the coke. The manganese was not removed in any greater quantities by this treatment than by the other method of aëration. The principal advantages of the riesler appeared to be its efficiency as an aërator and its action as a prefilter in lessening the period of sedimentation necessary before filtration.

EXPERIMENT IX.

Purpose.

In order to see what effect submerged contact or "scrubbing" would have on the manganese, the filter was backflooded to various depths.

Conditions.

Part.	Depth of submerged contact.	Depth of trickler.
a	3 feet.	5 feet.
b	4 feet.	4 feet.
c	5 feet.	3 feet.
d	6 feet.	2 feet.
e	7 feet.	1 foot.
f	8 feet.	......

The period of sedimentation and the rate of filtration were not changed.

Results.

AVERAGE OF ANALYSES.
(Results expressed in p. p. m.)

	Raw water.	Riesler effluent.	Filter effluent.
a. September 4 to 5.			
Dissolved oxygen	.40	8.10	.....
Free carbon dioxide	75.00	6.50	3.50
Iron	12.20	3.50	None.
Manganese	.92	.84	.76
b. September 11.			
Dissolved oxygen	.18	8.60	.....
Free carbon dioxide	55.00	5.00	4.00
Iron	10.40	4.00	None.
Manganese	1.12	1.12	1.04
c. September 12.			
Dissolved oxygen	.75	8.00	.....
Free carbon dioxide	67.00	....	7.00
Iron	10.40	5.60	None.
Manganese	1.12	1.04	.94
d. September 11.			
Iron	12.40	6.80	.20
Manganese	1.60	1.40	.96
e. September 22.			
Dissolved oxygen	2.00	6.90	.....
Free carbon dioxide	52.00	....	29.00
Iron	10.80	7.60	None.
Manganese	1.16	1.16	1.00
f. September 23.			
Dissolved oxygen	.40	3.30	.....
Iron	10.00	8.40	None.
Manganese	1.14	1.13	.99

Results.

The analytical results show that the "scrubbing" action of submerged contact with coke had no effect upon the manganese. In addition, the action of the coke as a prefilter was materially reduced, and the removal of carbon dioxide was much less complete.

EXPERIMENT X.

Purpose.

In order to determine the length of the period during which coke could be used as a trickler, before the deposit of ferric hydroxide became so thick that it would "break" and wash into the sedimentation basin, it was decided to make a continuous run, lasting, if possible, for several weeks.

Conditions.

The coke tower was used as a riesler (trickler). The period of sedimentation and rate of filtration were not changed.

Results.

AVERAGE OF ANALYSES. OCTOBER 2 TO 18.

(Results expressed in p. p. m.)

	Raw water.	Riesler effluent.	Filter effluent.
Dissolved oxygen	4.10	8.80	.....
Free carbon dioxide	56.00	....	4.00
Iron	12.60	4.00	.01
Manganese	1.28	1.08	.92

This experiment had to be stopped on the 19th of October, as the temporary water lines were dismantled by the company on account of the cold weather. For this reason the experiment was not continued until the riesler required flushing as had been planned. Yet the eighteen days' continuous run, added to the several weeks that the riesler had been used for ten-hour periods each day, showed that the deposit of ferric hydroxide on the surface of the coke was of such a nature that flushing would be required only at long intervals.

CONCLUSIONS.

The series of experiments showed:

That Lawrence water can be freed from iron by aëration followed by sedimentation and filtration.

That a minimum period of two hours' sedimentation in well-baffled basins should be allowed for, after aëration and before filtering.

That rapid sand filters may be used at high rates and still allow a complete removal of the iron.

That the manganese content of the water is only slightly reduced by aëration, sedimentation and filtration.

That the coke trickler is a very efficient aërator and an excellent prefilter.

That the manganese content of the water is not reduced by the action of the trickler aside from the slight removal effected, as before, by the aëration. That various periods of submerged contact, preceded by aëration, or that submerged contact without previous aëration, give no better results.

That the coke may be used as a trickler continuously over a long period before the deposit of ferric hydroxide becomes so thick that it "breaks" and the riesler requires flushing.

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BULLETINS OF THE ENGINEERING EXPERIMENT STATION.

*No. 1. *Part 1.*—A Ballistic Electro-dynamometer Method of Measuring Hysteresis Loss in Iron.
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*No. 3. Kansas Fuels: Coal, Oil, Gas.
Part 1.—Heating Values and Proximate Analysis of Coal.
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No. 6. Kansas Fuels: Coal, Oil, Gas.
Part 1.—Heating Values and Proximate Analysis of Coal. (Reprint of No. 3.)
Part 2.—Discussion of Sulphur Content of Bituminous Coal. (Reprint of No. 3.)
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No. 7. (In collaboration with the Division of State Chemical Research.) The Removal of Iron from Municipal Water Supplies.

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ENGINEERING BULLETIN No. 8.

The Measurement of Electrical Energy, Electricity Meters, Rates for Electrical Energy.

BY

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AND

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UNIVERSITY ENGINEERING EXPERIMENT STATION,
LAWRENCE, KANSAS.

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of Engineering Departments.

The Station designs to issue bulletins, of which this is the eighth number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

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View of Electrical Testing Room and Equipment, University of Kansas

PREFACE.

The preparation of this bulletin on the subject of the Measurement of Electrical Energy, Electricity Meters, Rates for Electrical Energy, is prompted by the many questions which have come to the electrical engineering department of the University of Kansas on items which concern the important matters of metering electricity at the customer's premises and rates for electrical energy. The asking of these questions has not been limited to the ordinary consumers of electricity, but quite often inquiries of the same general nature have come in from electrical plant owners, managers and operators, and it is felt that a paper briefly covering the items as noted above might prove of interest and use to many of the citizens of the state who are connected directly or indirectly with the generation and use of electricity.

No claim for considerable originality is made in the presentation of this bulletin, though some of the facts here stated have been established for the first time in our own electrical laboratories, which are well equipped for meter testing, and many of the others have been corroborated by us. In order that the material may be of general use it has not been limited to the report on work done by us only, but material from a large number of reliable sources has been drawn upon in order that the bulletin may present, in a concise manner, the answers to many of the questions along these lines which are continually coming up. Wherever feasible, credit is given to the independent source from which information is quoted, but there are numerous items for which it is not practical to give specific credit, and general acknowledgement of the use of such items is made here.

GEO. C. SHAAD.
C. A. JOHNSON.

LAWRENCE, Kan., June 1, 1916.

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THE UNIVERSITY OF KANSAS.
ENGINEERING EXPERIMENT STATION.

BULLETIN No. 8. JUNE 1, 1916.

The Measurement of Electrical Energy, Electricity Meters, Rates for Electrical Energy.

By GEO. C. SHAAD, *Professor of Electrical Engineering*, and
C. A. JOHNSON, *Associate Professor of Electrical Engineering.*

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BY

GEO. C. SHAAD and C. A. JOHNSON.

THE MEASUREMENT OF ELECTRICAL ENERGY.

Electrical Units.

A complete system of electrical units has been established for use in indicating electrical quantities, and the definiteness of these units and the accuracy with which electrical quantities may be measured is responsible, in a considerable degree, for the rapid advances which have been made in electrical engineering during the last quarter of a century. The electrical units are all based upon the physical units of length, mass, and time; that is, upon the centimeter, the gram, and the second. Units as based directly on these quantities are known as "fundamental" units or as "C. G. S." units. In many instances the units, as expressed in their fundamental form, are not well adapted to application in the measurement of electrical quantities as we ordinarily deal with them, and a second set of units, known as "derived" units, or "practical" units, has come into existence. Many of these derived units bear the names of noted scientists, as, for example, the watt, the ampere, the ohm, etc., and it is these practical units in which we are the more directly interested.

We need not be concerned with the units for all electrical quantities in our consideration of the measurement of electrical energy, but the units of electrical current, resistance, electromotive force or potential, power, and energy, should be given some consideration.

THE UNIT OF CURRENT. The definition connecting the fundamental unit of current with the units of length, mass and time is: The *fundamental unit of current* is that current which, when flowing through a conductor one centimeter in length and formed into the arc of a circle one centimeter in radius, will cause a unit force (the dyne, the force necessary to give an acceleration to one gram of one centimeter per second per second) to act upon a unit

magnet pole at the center of the arc. A unit magnet pole, in turn, is a pole of such a strength that it will act upon another unit pole at a distance of one centimeter with a force of one dyne. The derived or practical unit is the ampere, defined as one-tenth of a fundamental unit. From this we have the "international ampere," the unit in universal use. This is defined by the International Electrical Congress, held in London in 1908, as follows:

"The *international ampere* is the unvarying electric current which, when passed through a solution of nitrate of silver in water, deposits silver at the rate of 0.00111800 of a gram per second."

The silver voltameter as a method of fixing the unit of current was preferred to other possible methods, but the specifications under which the silver voltameter for the absolute measurement of current shall be prepared are not as yet specifically indicated, and in practical work we are at present depending upon the standard primary battery cell and the standard of resistance to establish our unit of current. The relation between the current and the electromotive force and the resistance for an unvarying current is expressed by Ohm's law: *Current equals electromotive force divided by resistance.* Definitely knowing the electromotive force and the resistance of the circuit, we can establish the current.

THE UNIT OF RESISTANCE. The *fundamental unit of resistance* is such a resistance that, when an electrical pressure of one unit is maintained across its terminals, a unit of current will flow through it. The practical unit of resistance is the ohm. One ohm equals 1,000,000,000 (10^9) fundamental units of resistance. The "international ohm," again the unit universally accepted, is defined by the International Electrical Congress of 1908 as follows:

"The *international ohm* is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.300 centimeters."

THE UNIT OF ELECTRICAL PRESSURE OR ELECTROMOTIVE FORCE. An absolute or *fundamental unit of electromotive force* is the electrical pressure set up in a conductor which is moved in such a manner and at such a rate as to cut across one magnetic line of force in one second. The practical unit of electrical pressure is the volt and the volt is 100,000,000 (10^8) fundamental units. The "*internation volt*" is the unit of electromotive force in universal

use, and this is defined by the International Electrical Congress of London, 1908, as follows:

"The *international volt* is the electrical pressure which, when steadily applied to a conductor the resistance of which is one international ohm, will produce a current of one international ampere."

It is thus seen that, while the fundamental definitions for the units of current, resistance and voltage are based upon the relations of the electrical quantities to the centimeter, the gram and the second, the practical units are multiples or submultiples of the fundamental units. Again, while the fundamental units define the unit current and the unit electromotive force, leaving the unit resistance to be established by Ohm's law, the international units directly define the ampere (unit of current) and the ohm (unit of resistance) by physical standards and leave the establishment of the electrical pressure to Ohm's law. The international ampere and the international ohm are known to be in very close agreement with the ampere and the ohm as expressed in terms of the fundamental units.

In the absence of definite specifications for the preparation of a silver voltameter for the absolute measurement of current, we have, since January 1, 1911, been using the international volt as 1/1.0183 of the pressure developed by the Weston normal cell when at a temperature of 20° C. The Weston normal cell is a standard primary battery cell which is prepared under definite specifications, and when so prepared gives a definite electromotive force as defined above. Thus, as already stated, we reproduce the unit of electrical pressure and of electrical resistance and derive the unit of electrical current through the relation expressed by Ohm's law.

Electrical Standards.

GOVERNMENT STANDARDS. The fundamental electrical standards are, then, the Weston normal cell and the mercury ohm, and from these standards we may pass to standards for current, power and energy. The maintenance of electrical standards for the United States is in the hands of the National Bureau of Standards at Washington, D. C.

LABORATORY STANDARDS. Inasmuch as the standards for electrical pressure and electrical resistance are reproducible only in the more extensive and completely equipped laboratories, standards which are constant in their value and more portable in their nature are prepared for the use of electrical laboratories,

and such standards are in the form of Weston standard cells, portable type, and resistance coils which may be compared with the standards at the National Bureau of Standards, Washington, D. C., and certified by this Bureau as to their exact value. By maintaining at least three units for each standard and intercomparing these units at frequent intervals, the change in any one unit can be immediately detected, and this unit, or preferably the complete set, can be sent in to the Bureau of Standards for check and a new certification. Figure 1 shows the general appearance of such portable standards, these particular units serving for the primary standards for the electrical engineering laboratories at the University of Kansas. Such certified standards are not used for regular testing work, but are employed only for checking other standards similar in nature, and in turn used as working standards. By means of such working standards and suitable auxiliary equipment, instruments such as voltmeters, ammeters and wattmeters, used in regular commercial measurements, may be calibrated.

THE UNIT OF POWER. Power is the rate of doing work, and the electrical unit of power is the *watt*. Again, the *international watt* is the unit in universal use, and this unit is defined by the International Electrical Congress, London, 1908, as follows:

"The *international watt* is the energy expended per second by an unvarying electric current of one international ampere under an electrical pressure of one international volt. The kilowatt equals 1000 watts, and a horsepower, the mechanical unit of power, is the equivalent of 746 watts."

THE UNIT OF ELECTRICAL ENERGY. Energy involves the item of time that work is being done, as well as the rate at which it is being done, and hence the practical unit for electrical energy is the energy expended by one watt in one second, or the watt-second. In commercial work we generally employ the kilowatt-hour, which, as the name implies, is the energy expended by 1000 watts for a period of one hour. Often the term kilowatt-hour, (abbreviated kw.-hr.) is contracted to "kilowatt," but strictly speaking the kilowatt can refer to power only, and not to energy. The terms power and energy are often used indiscriminately, but it is electrical energy, not power, which is paid for when our rates are expressed as a certain sum per kilowatt-hour. In certain classes of service a rate is fixed for the maximum demand for power, and this is a true power demand and is properly expressed in kilowatts. The mechanical unit of energy is the horsepower-hour, and this is the equivalent of .746 of a kilowatt-hour.

Methods of Measuring Electrical Energy.

Electrical energy is expressed conveniently in terms of the kilowatt-hour, and it may be measured commercially by means of indicating, recording or integrating instruments. By an indicating instrument is meant one by means of which the quantity to be determined is indicated at any particular instant by the position of a pointer or needle upon a dial or meter scale. If the quantity is a changing one the position of the needle is constantly changing, and there is no record of what the meter may have indicated at some previous instant. A recording instrument is one on which the readings from instant to instant are recorded, usually by means of a pen mark upon a paper scale, the pen actuated by the instrument proper and the scale moved by a clock mechanism. By an integrating instrument is meant a meter in which the product of the quantity to be measured multiplied by the elapsed time is automatically recorded upon the instrument dial or dials.

Indicating voltmeters and ammeters may be used for the measurement of electrical energy if the system is a direct-current one, or if it is an alternating-current system of a fixed and known power factor. Simultaneous readings of the voltmeter and the ammeter, taken at equal intervals of time, indicate, by their product, the power at the time of reading. The average of such indications of power, multiplied by the elapsed time, is a measure of the electrical energy. In the case of an alternating-current system with a power factor of less than unity, the result as obtained from the product of the current and voltage must be multiplied by the power factor to give true power. If the power factor is variable, then an indicating power-factor meter would be necessary, and its reading should be taken with each reading of the current and the voltage, but this method has no application in practice. If an indicating wattmeter is used, the average of the readings of the wattmeter is multiplied by the elapsed time to obtain the energy. If the load is fluctuating rapidly the readings of the indicating meter must be taken at short intervals if considerable accuracy is desired in the results. As a rule, the use of indicating instruments for the measurement of energy is limited to special tests or for the calibration of integrating instruments.

Recording instruments give a permanent record of the particular quantities which they measure from instant to instant, but these records must be averaged and the proper calculations made

to obtain kilowatt-hours for the required interval of time. Aside from not requiring an observer in constant attendance, they present no distinct advantage over the use of indicating instruments.

While it is possible, then, to measure electrical energy by means of proper combinations of indicating or recording instruments, such instruments are not resorted to for the regular work of determining electrical energy, but some form of integrating meter, known as a watt-hour meter, is used in preference. Such integrating watt-hour meters are available for all of our standard distributing systems. They preferably are made direct-reading, and will indicate the energy used by a particular installation to a degree of accuracy which is quite acceptable commercially. Where the method of charging for electrical energy is one which involves the maximum demand for power, as well as for the kilowatt-hours of energy used, special means for recording the maximum demand may be necessary. Such means consist of separate demand meters or special attachments for the integrating instruments, whereby a record of the power demand from time to time is obtained.

ELECTRICITY METERS.

The watt-hour meter, then, is the standard form of instrument in use for the measurement of the electrical energy used by any particular installation, whether of lamps, motors, heating devices, etc., or any combination of these. Watt-hour meters are manufactured for either direct- or alternating-current circuits and for all of the standard distribution systems, including three-wire direct-current and polyphase alternating-current installations. In their standard form they indicate, by suitable dial readings, the kilowatt-hours of energy used by the installation up to the time of the reading of the meter. In checking their accuracy they are compared with standard instruments, indicating or integrating, which, in turn, have been compared with primary standard cells and resistances as certified by the National Bureau of Standards at Washington.

It is not the intention of this bulletin to describe in detail the various makes of watt-hour meters which are on the market, but the general principles involved should be given at this point.

Watt-hour meters may be divided into three general classes: (1) *Commutator meters;* (2) *mercury meters;* (3) *induction meters.*

The first and second of these types may be used for either continuous (direct) or alternating-current circuits, but at present the general practice is to confine their use to direct-current installations and to use the induction type of meter for all alternating-current work.

In all types of meters there is a rotating element, the speed of which, at any instant, is proportional to the power demanded, and the movement of this rotating element is transferred to a train of gears which actuates the instrument dials. The torque upon the rotating element must, then, be in proportion to the power demanded by the circuit, and the main meter parts are designed to accomplish this. If the meter is to be actuated on light loads, however, there must be some additional device which will produce a torque just sufficient to overcome the friction in the meter bearings. Such devices are known as compensating devices or light-load adjustments. Finally, there must be some retarding device, the function of which is to keep the speed of the disc in direct proportion to the power demanded by the installation, and hence to the torques exerted upon the rotating element. The compensating devices vary in their nature, depending upon the type and manufacture of the meter, but the retarding device invariably consists of a metal disc, light in weight, revolving between the poles of one or more permanent magnets. The movement of this disc in the magnetic field produces eddy currents in the disc, and these, in turn, act to retard the motion which produces them. The position of the magnet with respect to the disc determines the exact amount of retardation that is exerted at any given speed.

The Commutator Type of Meter.

The commutator type of meter is, in principle, nothing more than a shunt type of direct-current motor without iron in either field or armature. The armature circuit, with suitable external resistance and the light-load compensating circuit, is made the potential or shunt circuit, and the main field coils are connected in series with the load. In the case of three-wire direct-current meters the field circuit is divided into two equal parts, one part connected in each of the outside wires of the main circuit, and the potential circuit is connected across the total voltage of the system. The compensating device for taking care of friction consists of a small coil, in series with the potential circuit as mentioned above, placed in a position similar to that of the series field coils, and for producing a field which will cause the moving element to tend to

rotate in the normal direction. The adjustment of the effect of the compensating device is by means of shifting the position of the coil with respect to the armature or by changing the number of effective ampere-turns in it.

In some types of commutator meters the total load current is carried through the field coils, and this makes an expensive construction if the instrument is of large current-carrying capacity. In other types an external shunt is used so that only a part of the total current passes through the field coils. Objections to the shunt type are that the contact resistance at the terminals of the shunt leads may vary, and a variation in this resistance will result in inaccuracies in the recording of the meter.

Commutator meters may be affected by stray magnetic fields unless special precautions are taken to guard against such effects. In important switchboard meters the effect of stray fields must be prevented. One method of neutralizing the effects of stray fields is to construct the meter with two parts to the armature, these parts arranged astatically; that is, so that, if lying in the same magnetic field, the effects of the two parts are opposed to each other and no movement results. As regards the field caused by the field coils of the meter, the one-half of the armature is in the reverse of the field of the other half, and the two parts act together to produce rotation. As a further refinement the retarding disc and magnets may be enclosed within a magnetic shield. Different manufacturers have different methods of preventing the effects of stray fields, of providing for the light- and heavy-load adjustments, etc., and these details may be learned from the descriptive catalogues published by the various makers.

The commutator type of meter may be used on alternating-current circuits if the potential circuit is made practically non-inductive, but its use for such circuits is very limited at present on account of the excellent features of the induction type of meters for this service.

Some disadvantages of the commutator type of meter may be mentioned, such as a heavy moving element, resulting in a considerable friction and wearing of the jeweled bearings, and high value and possible variation in the commutator brush friction. Diamond jewels, or the combination of steel ball pivots with sapphire jewels, have been resorted to to reduce wear on the bearings and gold commutators, small in diameter, and silver-tipped brushes are used in the construction of some important meters. Meters for small installations do not possess such refinements.

The Mercury Type of Meter.

In the mercury type of instrument the torque upon the rotating element is produced by a current flowing radially in a disc, the disc in turn being situated in a magnetic field in such a manner that the current in the disc reacts upon this field. The function of the mercury is to provide a path for the current to and from the disc. If the current in the disc is proportional to the line current and the magnetic field is proportional to the line voltage, then the torque produced is proportional to their product and to the power. In a meter with a suitable compensating and retarding device the speed of the disc should be proportional to the power at all loads, and the number of revolutions of the moving element in a given time should be a measure of the total energy for that time. The disc is mounted in a chamber of mercury, the mercury, as already stated, serving to lead the current into and out of the disc, and the buoyant effect of the mercury is utilized to float the moving element in such a manner as to reduce bearing friction to a minimum.

In the direct-current instrument the line current, if not in excess of about ten amperes, is led directly through the mercury chamber with its current-carrying disc. If the meter is of larger current capacity an external shunt is applied, and at full-rated load the current passed through the meter proper is in the neighborhood of five amperes. The strength of the magnetic field in which the disc is rotated is made proportional to the line voltage by properly disposed coils. In the alternating-current instrument the disc current is made proportional to the line voltage, and the field is established by the line current flowing through the proper series field coils.

Compensation for the friction at light loads can be accomplished in the direct-current meter by shunting a small portion of the potential current through the disc, or a thermo-couple, heated by the current in the potential circuit, may be introduced in such a manner as to send the desired amount of current through the disc when the line current is zero.

The Induction Meter.

The induction meter, as its name implies, operates upon the principle involved in the induction motor. By suitable devices an alternating magnetic field, proportional to the line current, and a second alternating magnetic field, proportional to the line voltage, are established, and these fields, if acting alone and with

the power factor of the load as unity, are 90 degrees in their relative time-phase relation and are established in two different positions mechanically. A disc, free to rotate, is placed so that it is subject to these two fields, and the shifting of the combined or resultant field as produced by the current and potential windings induces currents in the disc, and these in turn produce a torque which is proportional to the product of the current, the potential, and the cosine of the angle between them; that is, to the power factor. Since the product of these three quantities represents the true power in the circuit, the torque, and hence the speed, with proper compensating and retarding devices, is proportional to the power. Differences in individual meters are in the mechanical construction, in the methods used to give a 90-degree relation between the current in the line coils and the potential coils when the power factor is unity, and the methods used for overcoming friction at light loads or the compensating devices.

Fig. 2 illustrates the general appearance of the standard direct-current watt-hour meters now on the market. Fig. 3 illustrates a similar line of induction meters. The meters shown in these illustrations are for standard voltages and frequency, and are of moderate capacity.

Advantages and Disadvantages of the Different Types of Meters.

In general the advantages and disadvantages of the different types of meter which are available are as follows:

Commutator Type.

Advantages:

- Can be used on either direct- or alternating-current circuits if the potential circuit is made highly noninductive.
- It is correct at any power factor or frequency.
- It is simple in construction.

Disadvantages:

- The commutator and bearing friction is high.
- The moving element is necessarily heavy.
- The meter losses are relatively high.
- The meter is expensive in large current-carrying capacities unless external shunts are used, and the use of external shunts introduces the possibility of change in resistance of the shunt circuit through variable contact resistance.

Mercury Type.

Advantages:

- It possesses no commutator.
- Bearing friction is low on account of the buoyant effect of the mercury.
- It is small in size.
- It can be used on any frequency.
- It is not affected very seriously by vibration.

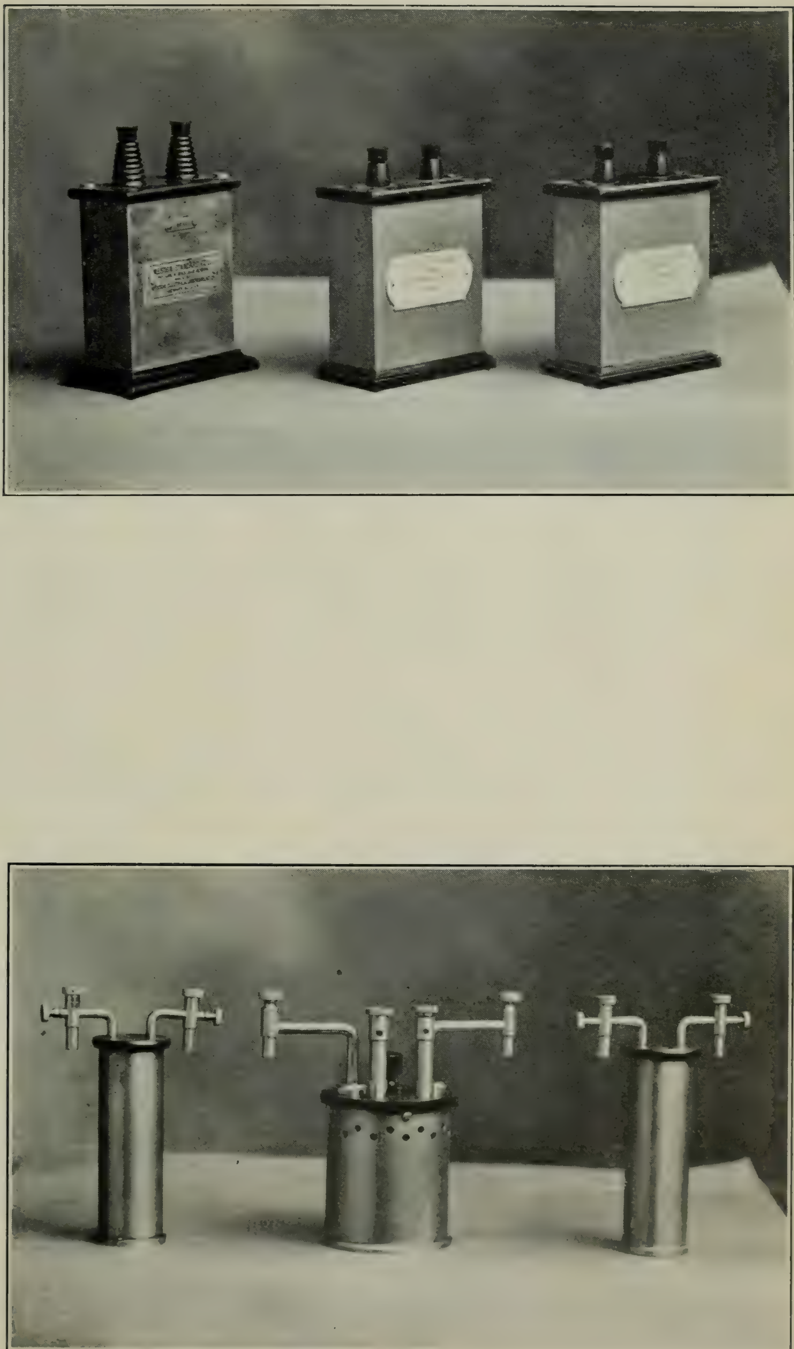


FIG. 1.

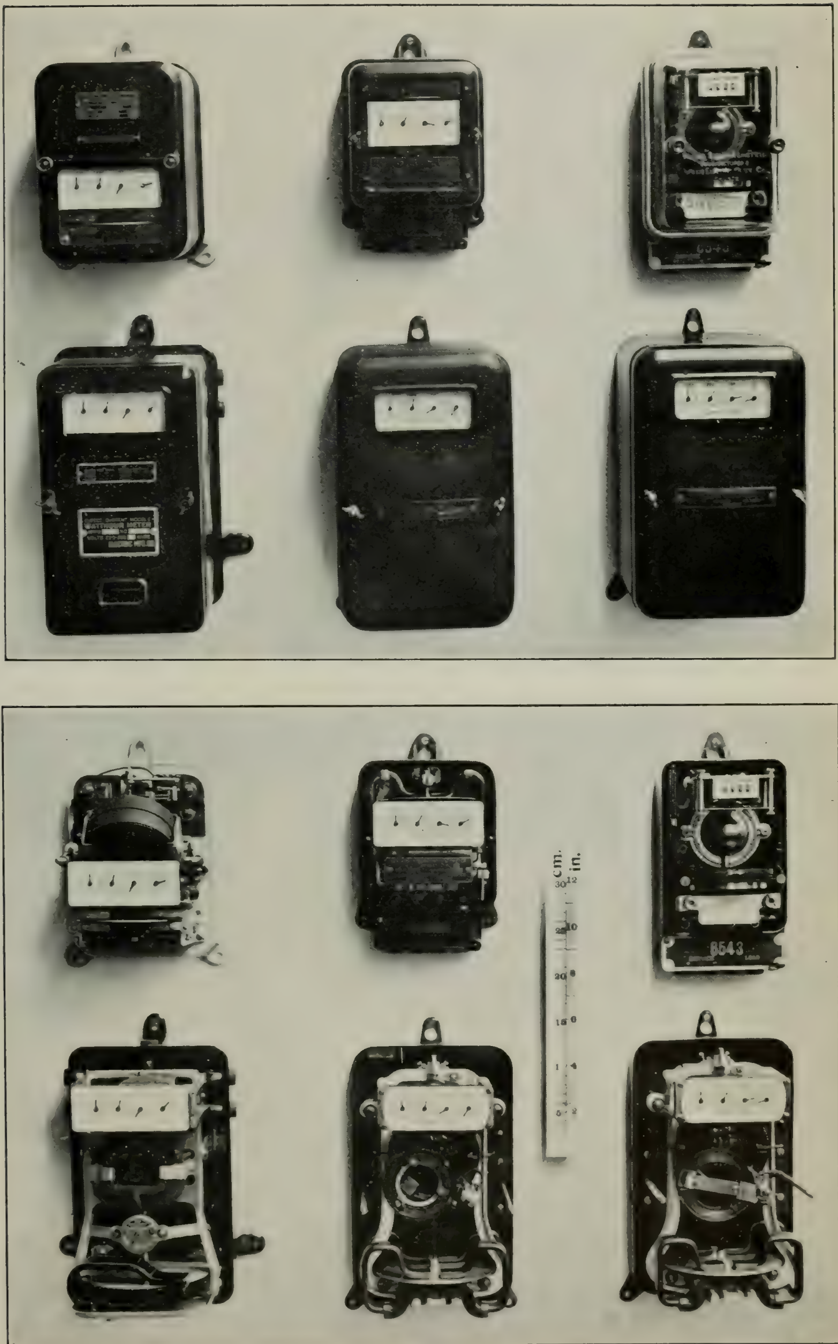


FIG. 2.

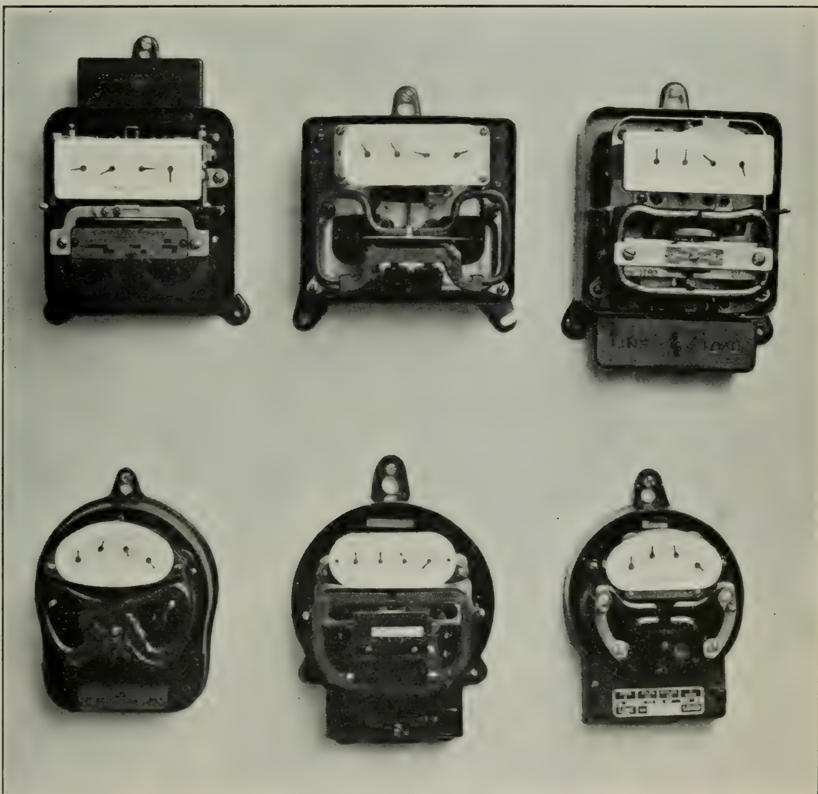


Fig. 3.

FIG. 3.

Disadvantages:

The torque developed is small.

The mercury may cause a change in the friction by amalgamation, oxidation, and the collection of dirt or dross around the guide bearing in the mercury chamber.

INDUCTION TYPE.

Advantages:

It possesses no commutator.

It is made in small sizes.

The moving element is light.

It is simple in construction.

It is low in first cost.

It maintains its calibration in an excellent manner.

Disadvantages:

The torque developed is small.

Vibration of the disc may be set up by the action of the magnetizing coils.

It possesses some inherent errors due to variation in frequency, power factor, and wave form.

It can not be used on a direct-current circuit.

It can not be depended upon to maintain its accuracy on loads much in excess of its rating.

Sources of Error in Integrating or Watt-hour Meters.

There are certain errors which are inherent to all types of watt-hour meter, and these are: errors due to temperature changes, the effects of variation in potential, errors due to friction in bearings, and the effects of the weakening of the retarding magnets.

ERRORS DUE TO VARIATIONS IN TEMPERATURE. There are two changes in temperature which must be considered, the one the change in the temperature of the meter due to a change in the temperature of the surrounding air, and the other the changes brought about by the amount of current which is flowing in the series coils. As the meter is ordinarily constructed an increase in temperature tends to increase the resistance of the potential circuit, and consequently the current in this circuit is reduced, for a given applied voltage, thus causing an error in the recording of the meter due to a decrease in the driving torque. At the same time that an increase in temperature decreases the torque on account of a decrease in the current in the potential circuit, the retarding effect is reduced by the increase in the temperature of the retarding device, so that the errors, as introduced, are partially compensating. The total error is seldom greater than one per cent for a change in temperature of 18° F., the meter decreasing in speed as the temperature increases. By using an alloy of

—2

just the proper temperature coefficient for the construction of the potential circuit the error due to change in temperature could be decreased, but this is not considered essential for the practicability of the commercial meter.

Errors Due to Variation in Voltage. Changes in the potential result in slight changes in the temperature of the potential circuit, hence the errors of a temperature change are introduced to a slight degree. Again, it is difficult to so design the instruments that the reluctance of the magnetic circuits remains absolutely fixed, as the magnetizing forces vary and the field does not remain absolutely proportional to the magnetizing force as the voltage impressed upon the potential circuit varies. By proper design, however, this inherent error is reduced to a very small value and may be considered as negligible if the regulation of the potential of the circuit is within reasonable limits.

Errors Due to Poor Bearings. Poorly designed bearings or poor jewels or pivots will tend to cause the meter friction to increase with time, and, with a fixed compensation, the meter will tend to run slow after it has been in use for a considerable period. Where the rotating element is light in weight sapphire jewels can be used with safety, and the normal life of such a jewel in an induction meter of ordinary type and ordinary use is estimated at about ten years. In meters with heavy rotating elements the diamond jewel is preferred to the sapphire, and special attention must be given to the bearings to maintain the meter in good operating condition.

Errors Due to Weakening of the Retarding Magnets. Retarding magnets are of the permanent type, and the design of these magnets should be such that they will tend to retain their magnetism, and in addition they must be well aged before they are placed in the meters. The weakening of these magnets reduces the retarding effects and causes the meter to run fast. Severe short circuits, causing abnormal currents to flow in the field coils of the meter, are responsible for the weakening of the retarding magnets in some meters when otherwise they would not change their strength materially.

Meters in alternating-current circuits, referring more especially to meters of the induction type, are subject to additional errors as follows:

Errors due to change in power factor, the effect of change in wave form, the effect of change in frequency.

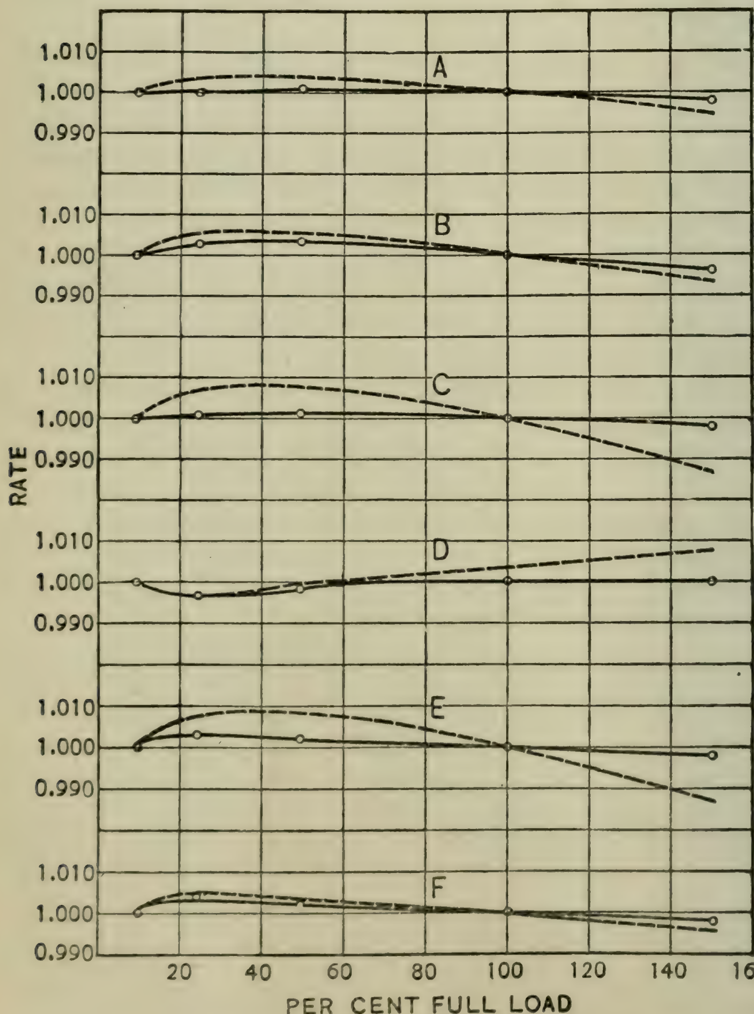
THE EFFECT OF CHANGE IN POWER FACTOR. The variation in power factor will have little effect if the relation of the current in the series and in the shunt coils are maintained at exactly 90 degrees time-phase relation when the power factor is unity; that is, when the load current is in exact phase with the voltage. The adjustment for a definite frequency, however, can be made quite exact, and when once made it seldom requires further attention. A change in frequency, however, results in a slight variation from the true 90-degree time-phase relation and a consequent error in the recording of the meter.

THE EFFECT OF VARIATION IN WAVE FORM. The effect of variation in wave form is to cause changes in the distribution of the rotating or shifting field, in the nature of the induced eddy currents and in the phase adjustment. A meter adjusted for accuracy on one wave form will not necessarily be accurate on a wave form which differes widely from the one on which it was tested. Fortunately the variation in the wave forms of the standard commercial systems is not great, and it is seldom that the errors introduced by irregular wave shape for the impressed potential need be taken into consideration.

THE EFFECT OF VARIATION IN FREQUENCY. The effect of variation in frequency on the accuracy of the induction type of meter is probably more important than the effects in variable voltage or of wave form, and it is important that the frequency be maintained within a reasonable degree of constant. A variation of as much as five per cent in the frequency may result in an error of one or two per cent, though the effect will not be as great as this in many makes of instruments.

The main sources of error for watt-hour meters have been very briefly discussed, and it remains to consider the results of tests of commercial meters to see to what extent the errors have been reduced by proper design and construction. For direct-current instruments we will quote from the results of a comparative study of American direct-current watt-hour meters made at the Bureau of Standards, Washington, D. C., by Messrs. Fitch and Huber, the complete details of which are set forth in vol. 10 of the Bulletin of the Bureau of Standards. Ten-ampere, three-wire instruments, three from each of six different makers, were subjected to this study, and the results, as regarding accuracy, are set forth in the curves in Fig. 4. These instruments are the same as those illustrated in Fig. 2. They were set to be accurate at one-tenth

and at full load, by means of the light-load and heavy-load adjustments, and the variation from accuracy at intermediate points is well shown by the curves. The curves, as here reproduced in the solid lines, are given as the ordinary load curves in which the full effect of the heating of the series field coils is not taken into consideration. With the full heating effect of the series coils the curves shown by the dotted lines result. In each case the maximum error is well within one per cent.



——— *Electrodynamic load curves.* - - - - - *The same with added effect of series coil heating*

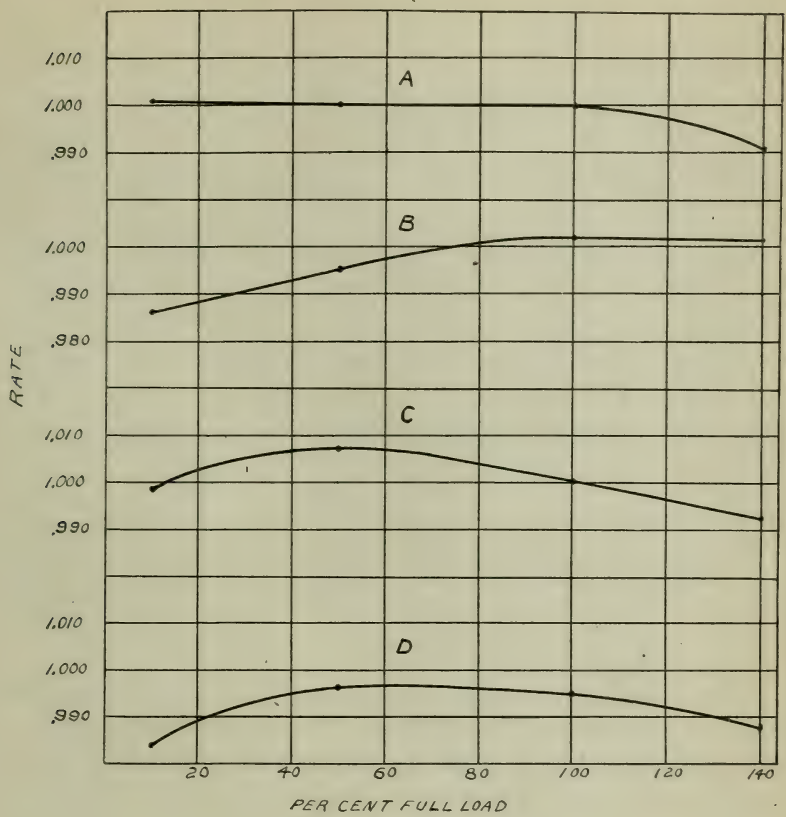

1.010
A
1.000
.990
B
1.000
.990
.980
RATE
C
1.010
1.000
.990
1.010
D
1.000
.990
20
40
60
80
100
120
140
PER CENT FULL LOAD

FIG. 5.

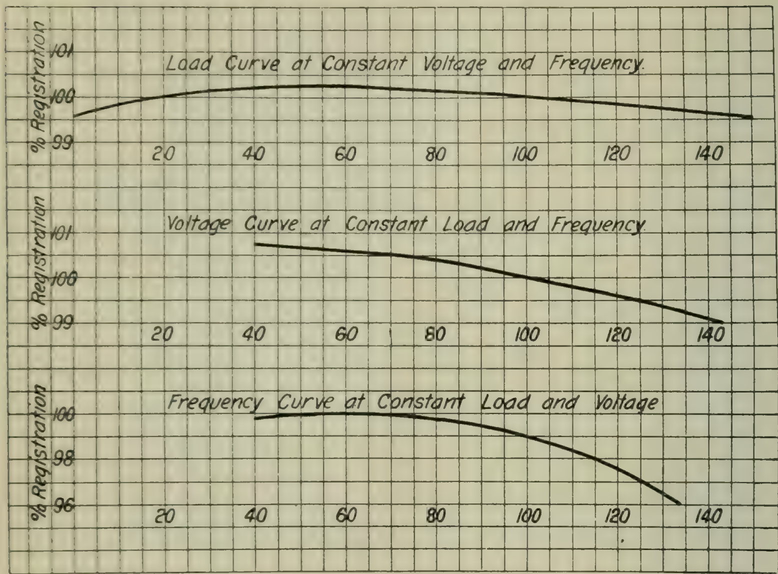


FIG. 6.

Similar curves showing the ordinary accuracy for induction meters are given in Fig. 5, these curves showing the results of tests carried out in the electrical laboratories of the University of Kansas on four different makes of induction watt-hour meters as purchased on the open market. These are the types of meters illustrated in Fig. 3. Fig. 5 shows the variation in accuracy which was found in new meters as purchased and with normal voltage, frequency, and an approximate sine-wave form of potential. The typical effects of changes in voltage and in frequency are illustrated by the curves in Fig. 6. Table 1 records the results of a complete set of laboratory tests made at the University of Kansas upon the four makes of meters referred to in Fig. 5.

TABLE I.—*Summary of results from a series of tests of watt-hour meters, induction type, made at the University of Kansas, 1915–1916.*

110-volt, 60-cycle, 5-ampere meters. Results accurate to .5 per cent.

METER No.	Watts to start registration.	Watts lost in potential coils.	Full load torque, m.m.—grms.	Change in registration due to change of temperature of air surrounding meter. change from —10° to +50° C.	Error due to irregular wave form.	
					Full load.	Light load.
				Per cent.	Per cent.	Per cent.
A	1.3	1.10	34.5	2.5	—.334	—.75
B	2.6	.85	38.3	4.0	+.336	+.197
C	1.3	.85	25.4	3.5	—.207	—.201
D	1.6	.90	39.2	5.0	—.903	—1.21

TABLE I—*Concluded.*

METER No.	Error due to change in power factor. P. F., .866, lagging current.		Error due to change in volts.				Error due to change in frequency.			
			100.		120.		65.		55.	
	Full load.	Light load.	Full load.	Light load.	Full load.	Light load.	Full load.	Light load.	Full load.	Light load.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
A	+.0833	+0.464	—.302	—.950	+.226	+.407	—.535	—0.91	+.303	+.076
B	+.417	—0.745	—.505	—.493	+.337	+.658	—.255	—.217	.369	.51
C	—.165	+1.22	—.171	—.340	+.257	+.506	—.325	—1.46	2.04	.194
D	+.296	+.703	—.202	—1.40	+1.01	+.650	—.511	—0.84	.717	.383

MAINTENANCE OF ACCURACY IN SERVICE.

The above curves are conclusive evidence that, as now manufactured, the present commercial meter is accurate within a fraction of one per cent for all ordinary uses, provided it is put in proper adjustment, and it remains to be seen how this accuracy is maintained in regular service.

The permanency of calibration depends upon constancy of friction, ratio of full-load torque to torque required to overcome friction, permanency of retarding magnets, rigid mechanical construction, and insulation. If the friction does not remain constant the light-load adjustment will not remain correct and the meter will be inaccurate, especially at light loads. The higher the ratio of the full-load torque to the friction torque the less will change in friction affect the accuracy at appreciable loads. Retarding magnets should be well aged, and, in as far as practical, placed so that severe short circuits on the system will not subject these magnets to a deteriorating effect. Rigid mechanical construction is necessary if the parts are to maintain their relative positions when the meter is subjected to the strains of service conditions. A slight misplacement of any of the parts may result in a considerable change in the meter rate. Good insulation is essential for the protection of the coils against the effects of overheating or of abnormal potentials, such as often result from lightning storms.

Evidence covering the permanency of calibration as it actually exists in practice must be taken from the results of a very large number of regular service tests, and the following table (Table II) gives as extensive and reliable data along this line as is at present available. This table is taken from the 1911 proceedings of the National Electric Light Association.

TABLE II.—*Meter accuracy record.*

(All meters with sapphire jewels.)

Type.	Load.	Period between tests, in months.	Meters tested.	Per cent.				
				Above 104% rate.	96–104% rate.	98–102% rate.	Below 96% rate.	Not running.
Induction	Full	12	40,000	1.2	97.0	86	1.8	0.4
	Light	12	40,000	2.5	92.0	78	5.5	0.7
Commutator, direct-current, 110-120 volts	Full	6	6,000	2.0	92.0	71	6.0	1.0
	Light	6	6,000	6.0	74.5	48	19.5	1.5
Commutator, direct current, 500 volts	Full	3	3,000	10.0	78.5	62	11.5	2.5
	Light	3	3,000	11.0	62.5	50	26.5	3.5

Common causes of inaccuracy: Increase in friction, weakened magnets, creeping (due to incorrect compensation, overvoltage, stray fields, incorrect connections), short circuits in windings, dirt, and moisture.

The general tendency is for meters to slow down; therefore it is to the direct interest of the seller of the energy to see that periodic and proper tests are made of the instruments by which he sells his product. It is not to be expected, however, that every meter shall be maintained in absolutely accurate adjustment, and the following limits are usually considered as reasonable:

Commutator types: 50 to 100 per cent load, 2 per cent either way; light load (10 per cent), 4 per cent either way.

Induction meters: 50 to 100 per cent load, 2 per cent either way; light load (5 to 10 per cent), 4 per cent either way.

There is a general tendency to limit the induction meter to 1½ per cent error for loads between 50 and 100 per cent and to an error of not to exceed 3 per cent on light load. When meters are being adjusted they should be brought to within 1 per cent of accurate at the light-load and the full-load points. Practice differs as to the service checks upon intermediate points, some companies testing at one intermediate point, estimated an average load for the particular meter, and others testing throughout the range and adjusting so that at no point will the meter be in error to exceed one per cent.

In some states the public service commissions have passed regulations governing meter installations and including the accuracy which shall be maintained in service meters, and the rules of the Railroad Commission of Wisconsin, passed after a careful study of the whole meter problem, are typical in this respect.

RULES OF THE RAILROAD COMMISSION OF WISCONSIN GOVERNING ELECTRIC METERS.

RULE 14. *Creeping meters.* No electricity meter which registers upon "no load" shall be placed in service or allowed to remain in service.

RULE 15. *Allowable error.* No electricity meter shall be placed in service or allowed to remain in service which has an incorrect register constant, test constant, gear ratio, or dial train, or which has an error in measurement in excess of four per cent between one-tenth and full connected load.

RULE 16. *Installation tests.* Each watt-hour meter shall be checked for correct connection, mechanical conditions, suitable location and accuracy of measurement at approximately three-quarters and one-tenth connected load by comparing the meter with approved suitable standards in its permanent position in place of service within thirty days after installation. Meters operating at low power factor shall also be tested at approximately the minimum power factor under which they will be required to operate. Meters installed with instrument transformers or shunts must be tested jointly with the transformers or shunts, otherwise the ratio of transformation of the transformers or calibration of the shunts, must be determined at least once every five years.

RULE 17. *Periodic tests.* Each watt-hour meter shall be tested according to the following schedule and adjusted whenever it is found to be in error more than one per cent, the tests both before and after adjustment being made at approximately three-quarters and one-tenth of the rated capacity of the meter. Meters operated at low power factor shall also be tested at approximately the minimum power factor under which they will be required to operate. The tests shall be made by comparing the meter, while connected in its permanent position on the consumer's premises, with approved, suitable standards, making at least two test runs at each load, of at least thirty seconds each, which agree within one per cent.

Single-phase, induction-type meters having current capacities not exceeding 50 amperes shall be tested at least once every twenty-four months, and as much oftener as the results obtained shall warrant.

All single-phase induction-type meters having current capacities exceeding 50 amperes, and all polyphase and commutator-type meters having voltage ratings not exceeding 250 volts and current capacities not exceeding 50 amperes, shall be tested at least once every twelve months.

All other watt-hour meters shall be tested at least once every six months.

In no case shall commutator-type meters having heavy moving elements and sapphire jewels be allowed to make more than 1,000,000 revolutions between tests. Where meters are found to register considerably in error when tested on the above schedule the commission reserves the right to order the particular meter or class of meters tested more frequently.

RULE 18. *Meter-test records.* Whenever an electricity meter is tested the original test record shall be kept, indicating the information necessary for identifying the meter, the reasons for making the test, the reading of the meter before being disturbed, a statement regarding creepage and the accuracy of measurement, together with all data taken at the time of the test. This record must be sufficiently complete to permit the convenient checking of the methods and the calculations. All utilities having more than 250 electricity meters in service shall maintain a meter record, numerically arranged, indicating approximately when the meter was purchased, its identification, its various places of installation, with dates of installation and removal, and the dates, with general results of all tests, and shall tabulate the results of tests according to types of meters and intervals of test, compiled monthly and annually.

RULE 19. *Meter-testing equipment.* Each utility furnishing metered electric service shall own suitable working standards for the testing of electricity meters, and either maintain these standards correct within one-half of one per cent or apply the proper correction to all tests. Secondary standards of some approved type shall be owned and maintained by each utility having more than 250 electricity meters in service.

RULE 20. *Request test.* Each utility furnishing metered electric service shall make a test of the accuracy of any electricity meter upon request of the consumer, provided the consumer does not request such test more frequently than once in six months. A report giving the results of each request test shall be made to the consumer, and the complete original record kept on file in the office of the utility.

RULE 21. *Referee tests.* Any electricity meter may be tested by an inspector employed by the commission, upon written application of the

consumer. For such test a fee shall be forwarded to the commission by the consumer when making application. The amount of this fee shall be refunded to the consumer by the utility if the meter is found to be fast beyond the four per cent limit. The amount of fee to be collected for these tests so made shall be $2 for each single-phase or continuous-current electricity meter having a voltage rating not exceeding 250 volts and a current capacity not exceeding 25 amperes without having instrument transformers; for other electricity meters having a capacity not exceeding 100 amperes the test fee shall be $4 per meter; for all others the fee shall be $8 per meter.

Type of Meter to be Used on the Various Distributing Systems.

For two-wire direct-current or single-phase alternating systems a meter with a single series or current coil and a single shunt or potential coil is used. The current coil should be connected in on the ungrounded side, so that if a partial ground occurs so as to cause a current leak on the customer's circuit the meter will take account of the energy required on account of such a defect. Both sides of the circuit should pass through the meter, so as to prevent the possibility of opening the potential circuit of the meter without disconnecting the potential from the customer's circuit as well. For the same reason, where direct-current circuits are of the higher potentials, say 550 or 600 volts, the added resistance necessary for the potential circuit should, preferably, be placed inside of the meter case.

Three-wire direct-current and single-phase circuits require meters with two series or current circuits, one in each of the "outside" wires. The potential circuit is preferably constructed for the potential of the two outside wires, and is connected across them, thus eliminating any error which might result from the unbalancing of the voltage on the two sides of the system if the potential coil of the meter were excited by the voltage between either of the outside wires and the neutral.

For polyphase alternating-current circuits it is best to employ one polyphase meter consisting of two single-phase elements, the moving parts of which are mounted on the same shaft. The total energy is then recorded upon one dial. If two separate meters are used it necessitates the proper addition of the readings of the two instruments to determine the total energy used by the circuit. With two meters and a low power factor, one of the meters runs in a direction the reverse of normal rotation, and this adds further complication to the calculations and to the explanations which must often be made to the customer.

Three-phase, four-wire systems are the exception, but special polyphase instruments for use on these systems are available. Three single-phase meters with their series coils in the three lines and their potential coils connected between their respective lines and the neutral will, by the sum of their readings, indicate the total energy consumed by such a circuit.

In alternating-current circuits, where the potential exceeds 440 volts, the use of series or current transformers for the current circuits and the use of potential transformers for the potential circuits should be resorted to.

Occasionally it is desired to determine the energy used by a three-phase, three-wire circuit when but one watt-hour meter is available. An indication of the total energy used by the circuit can be obtained if the load is balanced and the neutral point of the system is available. In case the neutral of the system is not available an artificial neutral can be obtained by making up two noninductive resistances, each equal to the resistance of the potential circuit of the watt-hour meter. The two resistances and the potential circuit of the watt-hour meter are connected to the three wires in a Y or star connection and the current coil of the instrument is inserted in the line wire to which the meter potential coil is connected. The total energy is then given by multiplying the reading of the meter by three. Such an arrangement as this should only be used temporarily and should not be used regularly for the measurement of energy.

The Capacity of the Meter to be Selected for any Particular Load.

An important point in connection with the metering of electrical energy is the question of the proper size of meter for any given installation. The meters, as a rule, operate at the highest degree of accuracy at points between 25 and 125 per cent of their normal rating. In the ordinary residence loads there are many hours of the day when the actual load is a small fraction of the maximum demand. If a meter of large capacity, compared with the maximum demand, is installed there is likely to be an error in the registering of the meter during the hours of light load. On the other hand, too small a meter might be injured by the load at periods of maximum demand. For such installations it is better to make the capacity of the meter equal to the estimated average demand and depend upon the overload capacity of the instrument to care for the peak loads.

For motor and sign-lighting installations the capacity of the meter should be equal to the rated capacity of the connected load.

Church lighting presents a special problem, as here we may have heavy loads for a considerable period and then relatively very light loads for much longer periods. In such cases the installation of two meters, one of low capacity and the other of a capacity equal to the average of the maximum loads may be considered, as the cost of the additional meter of low capacity, together with the necessary devices for interchanging the instruments with change in the character of the load, may be entirely warranted by the increased accuracy of the total measurements.

In the cases of combined power and lighting, even when the rate for the two classes of service is on the same basis, it is generally desirable to install two meters, one for each class of service, if the circuits are arranged so that this can be done at all conveniently.

In the case of the anticipation of an increased demand at a period some time in the future, it is better to install a meter for the present demand and then change to a larger size when the anticipated increase in demand becomes a reality.

It is not necessary that an operating company keep a large range of capacity of meters in stock, but a few sizes, carefully selected, will serve in the majority of cases, and then the following table may serve as a guide to the meter of the nearest adapted standard size to be installed. Remember that, in general, it is on the long-hour load that the highest accuracy is desired, and that it may be better to install a meter a little too small than to depend upon an instrument of a capacity far in excess of the normal load.

TABLE III.—*Average load for which meter should be installed for different classes of service.*

Character of load.	*Capacity of meter in per cent of connected load.*
Residence and apartment lighting	25
Elevator service	40
Factories, individual drive, churches, and offices	45
Factories, shaft drive, theaters, clubs, entrances, hallways, general store lighting	60
Restaurants, theatres, moving-picture machines, ice machines, pumps, compressors	70
Sign and window lighting, ventilating fans	100

The rating of watt-hour meters is on the current-carrying capacity of the series coils and the potential of the system, together with the frequency in alternating-current instruments. For certain classes of alternating-current apparatus the power factor

is less than unity and the actual current required for a given kilowatt load is higher than for unity power-factor apparatus. In the absence of specific figures covering the power factor of different classes of load the following table, derived from averages of many installations, may be used:

TABLE IV.—*Average values of power factors for different classes of alternating-current loads.*

Kind of load.	*Approximate power-factor, per cent.*
Incandescent lighting with small lowering transformer	90–95.
Alternating-current enclosed arc with constant current transformer	60–75—average 70.
Direct current metallic arc lamps with rectifier	55–70—average 65.
Induction motor, squirrel cage, single-phase, 1/20 to 1 hp	55–75—average 68 at rated load.
Induction motor, squirrel cage, single-phase, 1 to 10 hp	75–86—average 82 at rated load.
Induction motor, squirrel cage, polyphases, 1 to 10 hp	75–91—average 85 at rated load.
Induction motor, squirrel cage, polyphase, 10 to 50 hp	85–92—average 89 at rated load.
Induction motor, phase-wound rotor, polyphase, 5 to 20 hp	80–90—average 86 at rated load.
Induction motor, phase-wound rotor, polyphase, 20 to 100 hp	82–90—average 87 at rated load.
Induction motor loads in general	60–85—depends on whether motors are carrying rated load.
Small heating apparatus	Same as incandescent lamps.

The Choice of a Particular Make of Meter.

It is not always easy to make a choice of a particular make of meter, as there are several reliable companies manufacturing watt-hour meters, and these makers are devoting a great deal of attention and skill to their product along this line. The product of each maker has some special features which appeal to the various users to a different degree, and about all that can be done here is to call attention to some of the items which should be considered, and then the user can select the product of some one reliable maker which he believes, on the whole, best fulfills all of the functions of a good meter. The more important items to be looked into, some of which have already been discussed, are:

The losses in the meter, especially those in the shunt circuit, as these losses are going on continually, and while small in any one instrument, the total losses from this source for the system may amount to considerable.

The accuracy of the meter under various operating conditions, such as variation in voltage, frequency, etc., already discussed.

The permanency of calibration, already discussed.

The ease of adjustment and repair.

The construction of the instrument as a whole.

The cost. The cost is mentioned last because it is better to pay a little more, if necessary, for a good meter than to sacrifice accuracy, permanence of calibration, and low cost of maintenance for low first cost.

The study should include such matters as the freedom of the instrument from vibrations caused by the effects of the current in the meter coils, the weight of the rotating element as affecting the wear on jewels, the arrangement of the terminals as regards con-

venience of installation and good mechanical and electrical connections, the arrangements of parts and the sealing of the meter to prevent tampering, general appearance, etc.

To aid in making the choice of a particular make of instrument the customer may proceed along various lines in addition to the study of the claims made by the various manufacturers. The customer may purchase and install trial meters of different makes, but to get results from such trials requires considerable time, and unless several meters of each make, and all installed under similar conditions, are used, the results may not be fair criterion of what the instruments will actually do in the regular and average service. Correspondence with other companies concerning their experience, in regular operation, with different types of meters, may be of some help, but testimonials of this nature are liable to be prepared without a very deep study of the matter, and they may be unintentionally biased through the fact that the experience of the particular company may be limited to but one or two makes of instrument. Finally, a set of sample meters of different makes may be submitted to a set of impartial tests to be made by competent parties, and the report covering the results of these tests and giving the results of the study of the more essential items may be used in making the final decision. In any case, if the permanency of jewels, magnets and other items affecting calibration are to be passed upon, a considerable period for testing must be allowed.

Installation of Meters.

It is not only essential that a first-class product in the way of watt-hour equipment for recording the electrical energy used by the various customers be selected, but considerable care should be taken in the matter of the installation of the instruments at the customer's premises. The following points should be given special attention.

ACCESSIBILITY. The meter should be so placed that the customer is disturbed as little as is practical by the periodic reading of the instrument by the employee of the company. The meter should not be placed in a dark location or where there might be other special causes for the inaccurate reading of the instrument. Inaccuracy in meter readings and accounts is always a cause for dissatisfaction on the part of the customer. The location of the meter should not be such as to form an excuse

for the meter tester to slight his work, and this means such an installation that periodic tests of the instrument, in position, can be made with a minimum of inconvenience to both the tester and the customer.

FREEDOM FROM VIBRATION. Meters should not be placed on partitions or unstable supports of any kind, as mechanical vibrations may cause the meter to creep, even though the light-load adjustment is correct when such vibrations are absent. Mechanical vibration also has a tendency to increase the wear on jewels.

FREEDOM FROM MOISTURE AND DIRT. Meters should be so placed that they are free from dirt and moisture, either during periods of regular operation or when subject to periodic tests. It is not uncommon to find meters installed on the outside of buildings and under covered porches or in other sheltered locations. The object is to make the instrument readily accessible for the meter readers and testers, but care should be taken to see that the meter is well sheltered from the weather (this may require a special meter box in some cases), and the matter of the possible effects of change in temperature upon the accuracy of the meter should not be lost sight of when outdoor installations are contemplated.

The manner of making connections and the location of these connections should have some consideration because of the necessity of period tests of the meter. In many instances important meters are equipped with special connecting boxes arranged so that plug connections for inserting the necessary testing instruments can be readily made. Leads to and from the meter should be run in such a manner that the possibility of tampering with the circuits at this point will be reduced to a minimum. A good suggestion is to prepare general instructions for distribution to the local electrical contractors covering the matter of meter location and the installation of the leads going to this location.

Stray fields may affect the accuracy of meters, and care should be taken to see that the instruments are not unduly exposed to such fields. Switchboard meters which must be installed in the vicinity of heavy bus bars are especially constructed so as to be free from the effects of external fields, but the ordinary customer's meter is not so well protected, and care should be taken that it is not placed in the neighborhood of conductors carrying heavy currents, and the leads to and from the instrument should be run in such a manner as to keep the induced field in the neigh-

borhood of the meter to a minimum. This may be accomplished by keeping the two leads of a single-phase system close together. Avoid placing the meter within a loop made by the current-carrying conductors. Where more than one instrument is installed in a given locality keep alternating-current instruments at least fifteen inches apart, and direct-current instruments may well be separated to even a greater distance.

Care of Watt-hour Meters.

To insure that watt-hour meters are maintaining their accuracy periodic tests are required, and at the times of these tests any necessary cleaning or renewing of worn or injured parts should be attended to. It is to the interests of both the company and the customer that tests be made at not too long intervals and that such adjustments as will bring defective meters within the desired degree of accuracy be promptly made. Instruments which are not so reliable in the matter of permanency of calibration should be tested more frequently than meters known to maintain accuracy for long periods, and for this reason the schedule for testing direct-current instruments should call for shorter intervals between tests than for the induction type of meters. The larger meters, carrying the heavier loads, are of more importance than the small house meters, and the larger instruments should be tested more frequently. In general we may say that no meter should remain untested for a period much to exceed eighteen months and every meter should be tested at least once per 1,000,000 revolutions of the disc. The following schedule will serve as a general guide to the frequency of tests desirable for the ordinary types of meters:

TABLE V.—*Schedule for periodic testing.*

	Months
Modern types of induction meter single-phase, two and three-wire, up to 25 amperes capacity	18
The same as above but over 25 amperes capacity	18
Modern types of induction meters, polyphase type, up to 150 amperes capacity	12
The same as above but over 150 amperes capacity, 110 to 220 volts	6
Direct-current meters up to 25 amperes capacity, 110 to 220 volts	12 to 15
Commutator meters of over 25 amperes capacity and up to 150 amperes capacity, 110 to 220 volts	9 to 12
Commutator meters of over 150 amperes capacity and up to 600 amperes capacity, 110 to 220 volts	6
Commutator meters of over 600 amperes capacity, 110 to 220 volts	3
Commutator meters of 300 volts or over	3

Meter Testing.

Meters are tested for some one of the following purposes:

For insuring that the instruments are correct as received from the factory, tests are made in the laboratory upon the receipt of the instruments and before they are placed in stock.

Installation tests. Checks made immediately after installation on any customer's premises to insure accuracy of recording from the start.

Periodic tests. To insure that the meter is continuing to give proper indication of the energy used by the customer.

Retesting. Tests made shortly after the regular tester has completed his work and as an inspection of the manner in which the routine testing is being done.

Referee tests. Tests made by regular tester, but with outside parties refereeing tests and checking the accuracy of the work and of the instruments used.

Inquiry tests. Made between periodic tests in cases where the meters do not appear to be registering consistently or where tampering with the meter or accidents to the meter are suspected.

Special tests. Special investigation of various natures.

Installation tests, periodic tests, inquiry tests, retests and many referee tests are made on the meter in position on the customer's premises. Special tests are generally conducted in the laboratory.

The testing of a watt-hour meter is comparatively simple when suitable testing instruments and loading facilities are available. The simplest testing method is one where the instrument to be checked is compared directly with another watt-hour meter of known accuracy. Such meters of known accuracy are known as standard or test meters, also as "rotating standards," and they are carefully constructed, made self-contained for several different current ranges, and are quite portable.

These test meters can be taken to the customer's premises, where they are connected in the same circuit as the meter to be tested and different loads applied to the circuit. The number of revolutions of the dial of the instrument under test is compared with the revolutions of the dial of the test meter, and, with the constant of the test meter known, the condition of the meter under test can be determined. For tests of meters on the customer's premises some sort of portable devices which will serve as a load while testing is desirable, as it is not convenient in the majority of cases to use the customer's connected load for this

purpose. Portable load devices are made up in a variety of forms and are available in the market. Rotating standards are also available for direct-current watt-hour meters, but their use is not so general as the use of induction test meters for alternating-current work. The indicating voltmeter and ammeter, together with a stop watch, are more generally used for the checking of customer's meters when they are of the direct-current type. The desired load is applied for a period of at least one minute, during which time the revolutions of the disc, the voltage, and the exact current are noted. The product of the volts, the current and the exact time give the energy used, and this is compared with the number of the revolutions of the meter disc to determine the condition of the instrument.

Customer's meters of the ordinary range of currents and voltages are readily tested by the methods outlined above. With the larger installations for alternating currents, instrument transformers are introduced. Series or current transformers reduce the line current to a value, under normal rating, of about five amperes for the current coil of the instrument, and potential transformers reduce the voltage to a value in the neighborhood of 110 volts for the instrument potential coils. With the ratio of these transformers accurately known, and with the change in the phase angle between their primary and secondary qualities for the transformer negligible, the meter proper can be disconnected from the instrument transformer and tested as a low voltage, low current instrument, The "test constant" given with these meters refers to the instrument with its transformers, and the ratio of transformation of both current and potential transformer must, of course, be taken into consideration when determining the condition of the meter for tests made independently of the instrument transformers.

Large direct-current instruments supplied with current shunts may be tested independently of the shunts when the ratio of the total current to the current shunted through the series coils of the instrument is known, but care must be taken not to disturb the relation of the shunt-circuit resistance to the shunt resistance when this method of testing is used.

For large direct-current meters not using shunts, or for overall tests of large direct-current meters with shunts, it is desirable to have a low-voltage source of energy available for testing purposes. Storage coils are generally supplied for the purposes. The potential circuit of the instrument is then supplied with potential from

the operating system, but the current circuit is disconnected and is supplied with the direct current from the low-voltage source. In this manner meters of very large current-carrying capacity may be tested with a relatively small amount of energy.

Tests of meters, other than routine tests, are almost always made in the laboratory where the facilities for testing may be as elaborate as is desirable. Very small companies will not maintain testing equipment beyond a rotating standard and a few indicating instruments, and will depend upon more completely equipped laboratories in the vicinity for the maintenance of their instruments. Large companies, on the other hand, find it to their advantage to maintain extensive laboratories where the portable equipment can be maintained and its accuracy verified, and where all manner of special investigations can be carried out.

Testing Constants.

For the purpose of facility in testing, watt-hour meters are supplied with a test constant, by means of which the accuracy of the instrument can be determined from the revolutions of the meter disc, as already indicated. This constant is marked in some conspicuous place upon the meter, usually upon the meter disc. The ratio of the gear train connecting the revolution of the disc with the registry of the meter dial must, of course, be the proper one in every case. Meter makers are not entirely in accord in the manner in which the meter-testing constant is expressed. Generally it is stated as the watt-hours corresponding to one revolution of the meter disc, but in some instances it is stated as the watt-seconds per revolution of the disc, while in still other instances it is expressed as thirty-six times the watt-hours per revolution of the moving element.

For complete details covering the different makes of instruments the reader is referred to the descriptive material and instruction books issued by the manufacturers of the meter and to the Electrical Meterman's Handbook as published by the National Electric Light Association, New York City.

Meter Records.

Too much emphasis can not be placed upon the matter of suitable meter records for the operating company. The system of records need not be elaborate in the smaller systems, but it should be thoroughly organized and in sufficient detail to serve

the immediate uses of the company. Such records should cover meter tests, meter readings, meter ledger, and meter complaints. The following items, from which the ones essential to any particular system may be selected, is reproduced from the National Electric Light Association Proceedings for 1909:

LOCAL DATA.

Name of company. Date..19........
Test card number of slip number........................
District.. Station..
Route.................................... Order number.............. Trip number....................
Ledger.................................... Page.............................. Folio..............................
Bookkeeper.. Cost of repairs....................

CONSUMER.

Name..
Address..
Occupied as..
or character of place...
or business..
Time entered premises.. { ....a. m. / ....p. m.
Time left premises.. { ....a. m. / ....p. m.

SERVICE AND LOAD.

A. C. or D. C.. Phase..
Cycles.. Volts, left side..............................
Volts, right side...................................... Volts, outside................................
Service wiring.............................. { 2-wire. / 3-wire. House wiring.......................... { 2-wire. / 3-wire.
Kind of load or installation..
Connected load..
Lamps..
(Include space for various sizes and wattages.)
Motors.. Arc lamps......................................
Fans.. Heating device................................
Miscellaneous or special.......................... Normal load..................................kw.
Estimated average load in amperes..
State what current is necessary to carry full load..............................
Motor current..
Inrush.. Power factor..................................
Ground on house wiring.. { Tested clear. / Ground.
Short circuits..

METERS.

Serial or company's number...
Shop or manufacturer's number...
Catalogue number.............................. Style number..............................
Name of meter or maker...
Type.............................. Capacity—amperes..............................
Volts.............................. Location of meter..............................
Erected on.............................. In..............................
Occupied as.............................. Good..............................
Bad.................... Damp.................... Dusty....................
Accessible.............................. Inaccessible..............................
Used for lighting.............................. Power..............................
One division of first dial equals...

CONSTANT AND RATIOS.

Bill constant.................... Dial constant.................... Disc constant....................
Testing or calibrating constant...
Meter constant.............................. Gear ratio..............................
Current transformer ratio...
Potential transformer ratio...

METER TEST.

Meter as found.............................. Meter as left..............................

Per cent load........................	Standard Instruments.
Standard volts........................	
Standard amperes........................	
Standard watts........................	
Meter watts........................	
Revolutions........................	
Seconds........................	
Error or difference in watts........................	
Error in per cent { Fast........................	
Error in per cent { Slow........................	
Per cent of accuracy........................	
Average error in per cent........................	
Revolution of rotating standard........................	Rotating Standards.
Revolution of meter (correct number)........................	
Revolution of meter (actual)........................	
Per cent of accuracy........................	
Observed revolutions { Standard (*a*)........................	
Observed revolutions { Meter (*b*)........................	
True revolutions........ { Standard (*c*)........................	
True revolutions........ { Meter (*d*)........................	
(Per cent accuracy equals *c* divided by *a*.)	
Standard revolutions times constant (equals standard watts)........................	
Meter revolutions times constant (equals meter watts)........................	
Per cent accuracy........................	

TEST DATA.

Reason for test..............................
Date of previous test..............................
Class of test:
  Periodic or regular.............................. Initial—retest..............................
  Special—complaint.............................. Pick-up..............................
  Time of test from { ....a. m. to..............................a. m.
  { ....p. m. to..............................p. m.
  Tested with lamp bank.............................. Storage battery..............................
  Water rheostat.............................. Standard lamps number..............................
  Date calibrated.............................. Consumer's load..............................
Kw-hours used in test..............................
Method of test..............................
Formula for meter..............................
Tester..............................
Assistant..............................
Checked by..............................

INSTRUMENTS.

Ammeter number.............................. Voltmeter number..............................
Millivoltmeter number.............................. Wattmeter number..............................
Chronograph of stop watch.............................. Rotating standard number..............................

CONDITIONS.

As found:
  Dial reading.............................. Meter sealed..............................
    Seal..............................Terminal.
    ....Cover.
  Starting current..............................
  Creeping:
    Occasional.............................. Continuous..............................
    Backward.............................. Forward..............................
  Creeps due to..............................
  Rate of creep..............................
  Rev.............................. Min.............................. Sec..............................
  Hours per day..............................
  Watt-hours per day..............................
  Errors on starting load..............................per cent.
  Leveled..............................
  Shunt wire soldered..............................
  Tested field in shunt coil..............................
  Condition of Jewel.............................. Pivot..............................
    Top bearing.............................. Worm gear..............................
    Field coil.............................. Shunt coil..............................
    Resistance.............................. Armature..............................
    Commutator.............................. Brushes..............................
    Dial hands.............................. Disc..............................
    Constants.............................. In general..............................

As left:

All items under "As Found," and also the following:

Brush tension:

Light........................ Medium........................
Heavy........................ Right........................
Left........................

Adjusted:

Shunt coil or compensating device........................
Magnets........................ Disc........................
Armature........................ Shaft........................
Gears........................ Top bearing........................

Changed:

Jewel........................ Shaft........................
Pivot........................ Disc........................

Jewel:

Cup-diamond........................ Sapphire........................
Ball-bearing........................

Increase of volts above normal to cause creeping........................
Meter left........................
Service........................

The card system of records is preferred by many companies and the following form is given as a guide to the proportion of such cards. Using cards of different colors for different types of meters or for different forms of records will prove convenient in many cases.

.... CO. METER LIFE RECORD.

...... Co. No. ...... MAKE .... AMPS .... PHASE .... CONSTANT .... FACTORY No. ....
TYPE .... VOLTS .... AC DC WIRE .... 1 DIV. OF 1ST DIAL = ... KW-HRS. DATE PURCHASED............
REMARKS ....

ACTION.	DATE.	READING.	NAME AND ADDRESS.	NAME OF BUILDING.		LABORATORY TEST.			
Installed						L.	F.	Date.	By
Transferred					No.				
Disconnected				Store Dwelling Office Apart. Garage Shop		Seal.		Location of Meter.	
Reconnected			Dist. Town.	Front Center Rear Left Right	Floor.				
Removed									
Installed						L.	F.	Date.	By
Transferred					No.				
Disconnected				Store Dwelling Office Apart. Garage Shop		Seal.		Location of Meter.	
Reconnected			Dist. Town.	Front Center Rear Left Right	Floor.				
Removed									
Installed						L.	F.	Date.	By
Transferred					No.				
Disconnected				Store Dwelling Office Apart. Garage Shop		Seal.		Location of Meter.	
Reconnected			Dist. Town.	Front Center Rear Left Right	Floor.				
Removed									
Installed						L.	F.	Date.	By
Transferred					No.				
Disconnected				Store Dwelling Office Apart. Garage Shop		Seal.		Location of Meter.	
Reconnected			Dist. Town.	Front Center Rear Left Right	Floor.				
Removed									

Card, 5 by 8 in. Reverse side carries continuation of record.

RATES FOR ELECTRICAL ENERGY.

There are many ways in which charge is made for electrical energy and there are different theories as to what shall be the basis of the charges for any particular system of rates. State regulation of electrical utilities, in which the regulating commission has the power to fix rates for electrical energy, has become so general that a short discussion of rates and rate making is not considered amiss at this time.

Methods in use for charging for electrical energy may be classified under the following heads:

Flat Rate, based upon the connected load. This method of charging may be used when the load is of a known value and when it varies but little throughout the year and when no additional load will be connected without the knowledge of the company or municipality furnishing the electrical energy. Street lighting may well be charged for at a fixed rate per lamp per month, as the number of lamps and the energy used by the same type of lamp is practically the same year after year, and a monthly charge may be used.

Sign lighting is another type of service which may often be placed upon a flat rate.

Very small installations, when the revenue will be so small as to make the investment in a meter undesirable, is a field in which the fixed charge is sometimes introduced, but it is a question as to whether or not the flat rate should be used for such customers. Devices have been brought out for the purpose of preventing customers from adding to their load without the knowledge of the company or municipality furnishing the energy, but they have not received extensive application, the general experience having been that a device which effectively prevents the customer from exceeding his predetermined load is about as expensive to purchase and maintain as a meter would be.

Flat rates for loads of a variable character are bound to be discriminating, and when both flat-rate and metered customers are on the same system, the metered customer invariably has to make up for lack of return from the flat rate customer.

Straight-line Meter Rates. When a meter is installed the rate may be fixed at a definite amount per kilowatt-hour used, irrespective of the total monthly use or of the relation of the

maximum demand of the user to the total amount used. Such a rate is a great improvement over the flat rate and the accounting system is exceedingly simple.

The straight meter rate may be the same for all classes of customers, but generally recognition is made of the fact that the cost of service to all classes of customers is not the same, and separate meter rates for residence lighting, street lighting, power, etc., are made.

STEP METER RATE. This rate is in use in many instances, and, as in the block meter rate, it is made in recognition of the theory that users of large quantities of electrical energy are entitled to a lower rate than the smaller user, *i. e.*, the principle of wholesale and retail supply. While this is the case in many instances, it is not always true and there are cases where it does not apply either in theory or in fact. With the step meter rates the rate is made in steps, the rate per kw-hr. diminishing as the number of kw-hrs. used per month increases. As an example: say the rate is 10 cents per kw-hr. if the amount used is under 30 kw-hrs., 9 cents per kw-hr., if the amount exceeds 30 kw-hrs., and is under 100 kw-hrs., etc. With this rate the ridiculous condition exists that a customer's total bill may be made less by using a little more energy if he is very close to a change point, and in using the additional energy he succeeds in passing to the next successive step.

BLOCK METER RATES This rate overcomes the latter difficulty mentioned under step meter rates and at the same time the large user is given the advantage of a low rate per kw-hr. It can be illustrated as follows: 10 cents per kw-hr. for all energy used per month up to 30 kw-hrs.; for all energy used in excess of 30 kw-hrs. and not exceeding 100 kw-hrs., 9 cents per kw-hr., etc.

Step and block meter rates are in use in many cases where rates based upon the cost-of-service theory, as explained later, would prove too complicated in the accounting system and because the more scientific rates are difficult to explain to many of the customers.

DEMAND OR LOAD-FACTOR SYSTEM OF CHARGING. There are two theories of rate making neither one of which can be used entirely to the exclusion of the other. The one is known as the value-of-service theory, which is to some considerable extent the theory upon which freight rates are made up. It says, in essence, that the customers should pay in proportion to the value of the

service to them, it being assumed, of course, that the total sum finally derived by the central-station company will be no more than to allow a reasonable return upon their property. The cost-of-service theory is that each customer shall pay to the company in porportion to the cost of his particular service to the company. The difficulty of the latter theory comes in the determination of the cost of service, but for the bulk of the consumers it can be arrived at to a fairly close degree, and this theory is in practice by many of the state commissions who have given considerable attention to rate making. The value-of-service plan may be used in connection with the cost of service, say in the case where by the cost-of-service theory the rate would become so excessive as to prohibit a particular class of customers, but where, all things considered, it does not seem desirable to exclude this particular class. A rate less than that arrived at under the cost-of-service calculation may then be authorized for the particular class, but theoretically the deficit must be borne by the other classes. Demand systems of charging are for the purpose of making rates equal, as nearly as practical, to the cost of service for every customer.

The demand systems of charging, while they differ in the details of the manner in which they are made up, all recognize the fact that of the total cost of service a certain amount depends upon the plant investment and is independent of the amount of energy sold—that is, it is a fixed charge—while another portion of the total cost of service varies in proportion to the amount of energy generated or sold, and is a variable charge. Different terms are used to designate these two portions of the total cost. We speak of them as fixed and variable charges, demand and energy charges, capacity and output expense, etc. Because of the manner in which the operating costs may be divided up into capacity and output expense, we may consider each customer as entailing a certain fixed expense because of the size of his installation or his maximum demand, because the plant must at all times be of proper capacity to supply the demand of every customer, and he entails a certain variable expense due to the amount of energy which he actually uses. With a demand system of charging, then, the customer pays what amounts to a fixed charge, dependent upon his actual or estimated maximum demand, plus another rate for energy used, though the determination of his monthly bill may be worked up on a somewhat different basis.

To explain the demand system of charging in another way, we will define load factor as the ratio of the average load to the maximum load. The cost of generating energy per kw-hr. at the power plant would then be a minimum if the plant were run constantly at its maximum demand—that is, at unity load factor—because then the maximum kw-hrs. would be generated for the minimum of fixed charges, and the total charges, divided by the kw-hrs. output, would be a minimum. As the load factor is diminished the relative cost of energy is increased. The same items apply to the customer, and that customer which uses an average load more nearly in proportion to his maximum demand—that is, the long-hour user of a steady load—is entitled to a lower rate per kw-hr. than the customer who has a relative heavy demand, thus entailing large fixed charges for plant and distribution equipment, but who uses energy but a few hours each day and requires but a small amount of power excepting for a short interval during the peak demand.

If we admit that a demand or load-factor system of charging is desirable, there remains the matter of the determination of the cost of service and the details of the rate system.

The system may be: A fixed charge based upon the customer's demand, and an energy charge for the kw-hrs. actually used; or it may consist of a graduated rate per kw-hr., the rate depending upon the equivalent number of hours' use of the customer's demand; that is, if the demand is one kilowatt and the energy used for one month is thirty kw-hrs., then the equivalent hours' use of the customer's demand is thirty hours, etc. The result is the same in either case—the customer with the higher load factor obtains the lower kw-hr. rate as a whole.

For the determination of the customer's maximum demand, demand indicators may be used. These take a variety of forms. In some cases a separate meter, such as the Wright demand meter, named for one of the men instrumental in getting the demand system of charging introduced, is used; or, in other instances, a special device is combined with the watt-hour meter, such as a printometer, or some other demand-indicating attachment. A recording wattmeter, when its installation is desirable, serves as a demand indicator. With the demand indicator in use the customer is usually granted the privilege of having the instrument cut out of service for an occasional unusual demand which he may wish to make.

The addition of a device for indicating the demand is not always warranted, and estimated demands are in very general use for the ordinary customers. The basis of the estimate may be:

The demand may be considered as proportionate to the room area and a schedule worked out for different-sized structures and the uses made of the same.

The demand may be considered as a certain portion of the connected load, using a different portion of the connected load for different classes of customers. The Wisconsin railroad commission uses a certain proportion of the connected load, and designates this as the customer's *active connected load* instead of the customer's maximum demand.

Again, the demand might be based simply upon the number of rooms, irrespective of their size.

In any event the proportion which is used is an effort to approximate the customer's actual maximum demand, and when percentages of the connected load are used these percentages are the results of large numbers of actual observations in practice with demand indicators in position. The following classification in force in one of the Wisconsin cities is typical:

Class A. This class shall include residences, dwellings, flats, private rooming and boarding houses, and where the total connected load is equal to or less than 500 watts, 60 per cent of such total connected load shall be considered active; where the total connected load exceeds 500 watts, 33 1-3 per cent of the excess over and above 500 watts shall be considered active.

Class B. Sixty per cent of the total connected load shall be considered active. This class shall include banks, city and county buildings, churches, federal buildings, factories (including machine shops, blacksmith shops, tin shops, cigar factories, woodworking establishments, and other manufacturing establishments closing not later than 6 p. m.), freight and storage warehouses, garages, hotels, public, private and parochial schools.

Class C. Seventy-five per cent of the total connected load shall be considered active. This class shall include bakeries, barber shops, barns (private and livery), breweries, bowling alleys, book and notion stores, crockery and china stores, corridors and halls in office and apartment buildings when on a separate meter, candy and fruit stores, clothing and furnishing stores, dry goods stores, dressmaking shops, drug stores, depots, express offices, electrical-supply stores, flour and feed stores, furniture stores, grocery stores, grain elevators, dance and public halls, hairdressing and manicure parlors, harness shops, hardware stores, jewelry stores, laundries, meat markets, millinery stores, music stores, moving-picture shows, offices (commercial, professional and private), opera houses, photograph studies, plumbing shops, printing shops, restaurants, roller-skating rinks, shoe stores and repair shops, second-hand stores, stationery stores, tailor shops, tea and

coffee stores, tobacco and cigar stores, telephone offices, and all other consumers not otherwise specifically provided for in this schedule.

CLASS D. Eighty per cent of the total connected load shall be deemed active. This class shall consist of card and club rooms, lodge halls, pool and billiard halls, saloons, department stores.

CLASS E. The total connected load shall be considered active. This class will consist of flaming arc lamps used for street decorations, general street decorative lighting, signs, outline and window lighting.

Calculation of Suitable Rates.

Irrespective of the details of the method of making up the demand system of charge, the method of determining the cost of service is the same and it may best be illustrated by taking up a single case from actual practice. It will be evident from the following example that the plant records and accounting system must be fairly complete, and, of course, in cases where the records are not already available, reasonable assumptions must be made for the various items before proceeding with the many calculations. Details will not be the same for all consumers, but the example here selected completely illustrates the principle of arriving at the cost of service and of making a rate based upon such cost of service.

Assume a municipal plant in a town of 2500 population, supplying commercial light and power and street lighting, and combined with a waterworks plant, the pumping of water being by means of an electric motor. The valuation of the waterworks plant and the electrical plant must be determined separately. Many interesting problems come up in determining just how much belongs to the one and how much to the other plant, but we must confine ourselves here to the simple value of $43,500 arrived at for the electrical plant. The actual figures are taken largely from the Columbus, Wis., rate decision, 1913.

Interest, depreciation and taxes, together, are taken at 10½ per cent. This being a municipal plant, no profit is allowed. An amount to cover a reasonable return upon the investment should be added in the case of individual or corporation ownership.

The outputs per year at the station switchboard are as follows:

Electric pumping	29,622 kw-hrs.	13%
Street lighting	57,231 kw-hrs.	25%
Commercial lighting	122,000 kw-hrs.	54%
Commercial power	18,100 kw-hrs.	8%

The maximum demands at the station switchboard are as follows:

Electric pumping	17.2 kw.	7%
Street lighting	51.6 kw.	21%
Commercial lighting	151.5 kw.	62%
Commercial power	24.4 kw.	10%

The electrical energy as actually sold per year is:

Electric power for pumping, sold to waterworks at switchboard	29,622 kw-hrs.
Sold to street lighting system at switchboard	57,231 kw-hrs.
Sold to power consumers	14,270 kw-hrs.
Sold to commercial consumers	99,294 kw-hrs.

The total connected loads are as follows:

Commercial lighting	426 kw.
Power consumers	115 hp.
Street lighting	128 100-watt lamps, and 68 60-watt lamps.

Of the commercial lighting 52.8 per cent of the connected load is considered as active, the active connected load thus amounting to 225 kw.

The operating expenses, as divided between capacity and output charges, are as follows:

Classification.	*Capacity.*		*Output.*	
Electric generation	$2,395.32		$4,201.41	
Electric distribution	165.81		39.57	
Consumption	264.00		818.00	
Total (direct expense)	$2,825.13	(36%)	$5,058.98	(64%)
General expense	586.64	(36%)	1,042.91	(64%)
Undistributed	111.44	(36%)	198.12	(64%)
Interest, depreciation and taxes	1,683.02	(36%)	2,992.04	(64%)
Total	$5,206.23		$9,292.05	

The capacity charges must now be apportioned among the different classes of service on the basis of demand made by each class, and the output charges must be apportioned on the basis of the current used by each.

When this is done we have the following:

Apportionment of electric expenses to the different classes of service.

Classification.	Electric pumping.		Commercial lighting.		Commercial power.		Street lighting.	
	Capacity.	Output.	Capacity.	Output.	Capacity.	Output.	Capacity.	Output.
Electric Generation:								
Operating labor								
Steam generated								
Miscellaneous supplies and expenses	7%	13%	62%	54%	10%	8%	21%	25%
Maintenance of equipment								
Maintenance of buildings, fixtures, grounds.								
Total	$167.67	$546.18	$1,485.10	$2,268.77	$239.53	$336.11	$503.02	$1,050.35
Distribution:								
Operating labor								
Supplies and expenses								
Maintenance of distribution system	....	....	50%	50%	10%	10%	40%	40%
Maintenance of transformers								
Maintenance of meters								
Total	....	....	$82.91	$19.78	$16.58	$3.96	$66.32	$15.83
Consumption:								
Commercial lamp renewals	....	....	....	$391.00	....	....	....	....
Customer's premises expenses	....	....	$250.80	....	$13.50	....	....	....
Municipal lamp renewals	....	....	....	....	....	....	....	$427.00
Total	....	....	$250.80	$391.00	$13.50	....	....	$427.00
Total direct	$167.67	$546.18	$1,818.81	$2,679.55	$269.31	$340.07	$569.34	$1,493.18
General:								
General office salaries								
Miscellaneous general expenses	6%	10.8%	64.3%	53%	9.5%	6.7%	20.2%	29.5%
Railroad commission expenses								
Total	$35.20	$112.63	$377.21	$552.74	$55.73	$69.98	$118.50	$307.66
Undistributed:								
Insurance								
Stationery and printing	....	10.8%	64.3%	53%	....	6.7%	....	29.5%
Maintenance of buildings, fixtures, grounds,								
Total	$6.69	$21.40	$71.66	$105.00	$10.58	$13.27	$22.51	$58.45
Interest	....	....	....	....	....	....	....	....
Depreciation	....	....	....	....	....	....	....	....
Taxes	....	....	....	....	....	....	....	....
Total	$72.37	$128.66	$1,977.74	$5,315.03	$127.91	$227.39	$370.26	$658.25
Total all expenses	$281.93	$808.87	$3,380.16	$5,315.03	$463.53	$650.61	$1,080.61	$2,517.54

For pumping a flat rate is made as follows:

Total cost equals $1,090.80.
Kw-hrs. equals 29,622.
Rate per kw-hr., 3.68 cents (made 3.5 cents).

For commercial lighting the cost per kw-hr. for current is determined by dividing the output charge by the kw-hrs. sold; $5,315.03 divided by 99,294 equals 5.37 cents.

The capacity charge depends upon the number of hours the customer uses his active demand. If used for one hour each day the total kw-hrs. would be 365 multiplied by 225 equals 82,125, and the capacity charge would be $3,380.16 divided by 82,125 equals 4.12 cents.

If the active demand were to be used two hours each day the capacity charge would be reduced to 2.06, one-half of 4.12, etc.

We then have the following totals:

	Capacity charge, cents.	*Output,* cents.	*Total,* cents.
1 hour's use	4.12	5.37	9.49
2 hour's use	2.06	5.37	7.43
3 hour's use	1.37	5.37	6.74
4 hour's use	1.03	5.37	6.40
5 hour's use	.82	5.37	6.19
6 hour's use	.69	5.37	6.06
10 hour's use	.41	5.37	5.78

Of course a rate schedule could be made to include all of the above values, but this is unnecessary, and about three rates are found to serve very nicely. These would be 10 cents net for the first 30 hours' use of the active connected load, 8 cents net for the next 60 hours' use of the active connected load, and 6 cents net for all of the additional energy used.

The rate for commercial power may be determined as follows: The connected load is 115 hp. and the capacity charge is $463.51; therefore a fixed charge of $4.03 per hp. per year would cover the capacity charge. The charge for current should be the output charge divided by the kw-hrs. sold, or $650.61 divided by 14,270, or 4.56 cents.

If all street lamps are burned the same number of hours per year a flat rate per lamp can be readily made by dividing the total expense by the total number of watts connected, and multiplying this number by the watts rating of the different size units. Thus, there are 128 100-watt lamps and 68 60-watt lamps—a total of 16,880 watts, against a total charge of $3,598.15, or a charge of $21.30 per year for a 100-watt lamp and $12.78 for a 60-watt lamp per year.

Special Items.

When a customer is willing to dispense with his service during the normal peak load on the station—that is, when the customer, because of the nature of his demand, occasions no additional fixed charge on the plant or the distributing system because of his connected load—special rates somewhat less than for the regular customer can be allowed without discriminating against the customer who demands cotinuous service.

Discounts for prompt payment are not considered as variations in the rate, but the rate, after prompt-payment amounts are deducted, should make up the cost of service.

Unless the system of charging is one involving a fixed charge plus a charge for energy, a minimum monthly charge to cover the necessary cost of service, as is included in meter expense, accounting expense, etc., is usually recognized as equitable, and the amount of $1 per month for the ordinary customer is not considered excessive.

Rates in Force in Cities in Kansas.

A compilation of the rates in force in the majority of the cities of Kansas as of June 1, 1916, has been made, largely by Messrs. L. N. Smith and F. Haskins, and this compilation is hereby appended for reference. The schedules are incomplete in some cases and several towns are omitted because of the failure of the authorities to furnish their rate schedule. The population figures are taken from the 1910 census.

ABILENE. Population, 4340. Riverside Light and Power Company. Day and night lighting circuit, 110 v.; 220 v. motor circuit, 3 phase. Number of customers, 962.

STREET LIGHTING:

165 type C, series, 6.6 amp. lamps, all-night schedule........	$15.00 per year.
57 Mazda 40-watt lamps, all-night schedule................	15.00 per year.
228 Mazda 25-watt lamps, until 11 p. m....................	1.20 per year.

This last rate is based upon a six nights per month schedule, but the light company burns them the rest of the time at their own expense. Renewals are furnished by the company.

COMMERCIAL LIGHTING: Current rate, 10c per kw-hr.

Discount for lighting: 20c per light, 5 per cent discount; 30c per light, 10 per cent; 40c per light, 15 per cent; 50c per light, 20 per cent; 60c per light, 25 per cent; 70c per light, 30 per cent; 80c per light, 35 per cent; 90c per light, 40 per cent; $1 per light, 45 per cent; $1.20 per light, 50 per cent.

For basing discount on lighting, each 50-watt equivalent or fraction thereof will be considered one light.

Residence minimum, $1.50; business minimum, $1.

In addition on lighting bills of $1 or more paid by the fifth of the month, discount checks amounting to 10 per cent of bill are given, but no checks smaller than 5 cents are issued. These checks are good for face value in payment on lamps or other electrical appliances in the office of the company.

Flat rate: For a single 16 c. p. carbon lamp or equivalent, $1 per month for the first lamp and 50 cents for each additional lamp. (Practically all are on meters.)

COMMERCIAL POWER RATES:

Rate of discount for three-phase power; 20 to 25 kw-hrs., 5 per cent discount; 25 to 30 kw-hrs., 10 per cent; 30 to 35 kw-hrs., 15 per cent; 35 to 40 kw-hrs., 20 per cent; 40 to 45 kw-hrs., 25 per cent; 45 to 50 kw-hrs., 30 per cent; 50 to 55 kw-hrs., 35 per cent; 55 to 60 kw-hrs., 40 per cent; 60 to 65 kw-hrs., 45 per cent; 65 to 90 kw-hrs., 50 per cent; 90 to 150 kw-hrs., 60 per cent; 150 to 200 kw-hrs., 70 per cent.

Minimum rate, $1.50 per month.

Meters are owned and furnished free of charge by the company.

Energy is sold to the city of Enterprise in bulk.

ALMA. Population, 1010. Alma Light and Ice Company. Day and night lighting circuit 110 v.; 220 v., a. c. motor circuit. Number of customers, 147.

STREET LIGHTING:

40 Tungsten lamps, 40-watt; moonlight midnight schedule, $15 per year.

Renewals furnished by the city.

COMMERCIAL LIGHTING:

Meter rates:

First 10 kw-hrs	15c.
Next 10 kw-hrs	14c.
Next 10 kw-hrs	13c.

(One cent less for each additional 10 kw-hrs.)

Flat rate: 25c per lamp. (Very few connected.)

Power rates, none.

Minimum rate: $1 when consumer owns meter; $1.25 when company owns meter. Discounts, none. Meters are owned by both company and consumers.

ALMENA. Population, 702. Municipal electric light plant. Lighting circuit, night, 110 v., 60 cycles. Number of customers, 99.

STREET LIGHTING:

50 100-watt incandescent lamps, $12 per year, burning from twilight to midnight and from 5 a. m. to daylight. Renewals are furnished by city.

COMMERCIAL LIGHTING: Meter rate, 12c. per kw-hr.

Minimum rate, $1, including meter.

COMMERCIAL POWER: 15c. per kw-hr.

Discounts, none.

ARKANSAS CITY. Population, 10,000. Kansas Gas and Electric Co.

STREET LIGHTING:

140 Incandescent 60-c. p. lamps, all-night schedule	$13.20 each per year.
99 incandescent 80-c. p. lamps, all night schedule	17.40 each per year.
90 posts, 1-100-c. p. lamps, all-night schedule	36.00 each per year.

Renewals are furnished by the company.

LIGHTING AND POWER:

Meter rates:

1 to 24 kw-hrs. per month	10c. per kw-hr.
25 to 49 kw-hrs. per month	9c. per kw-hr.
50 to 99 kw-hrs. per month	8c. per kw-hr.
100 to 199 kw-hrs. per month	7c. per kw-hr.
200 to 299 kw-hrs. per month	6c. per kw-hr.
300 and over kw-hrs. per month	5c. per kw-hr.
Minimum monthly charge for lighting	$0.50
Minimum monthly charge for power	1.00

If bill is not paid by twentieth of month following that in which service is rendered 30 per cent is added.

ADVERTISING LIGHTING:

Flat rate: Consisting of sign, outline, display window and spectacular lighting, burning from dusk until midnight, every night, under power company control. Per watt rated capacity of connected load per month, 1c. net; where lamp renewals are furnished an addition of 4c. per watt.

INDUSTRIAL POWER (Customer's option):

Meter rate:

For first 100 kw-hrs. per month	8c. per kw-hr., net.
For next 100 kw-hrs. per month	6c. per kw-hr., net.
For next 100 kw-hrs. per month	5c. per kw-hr., net.
For next 200 kw-hrs. per month	4c. per kw-hr., net.
For next 1,000 kw-hrs. per month	3½c. per kw-hr., net.
For next 3,500 kw-hrs. per month	3c. per kw-hr., net.
All over 5,000 kw-hrs. per month	2½c. per kw-hr., net.

Minimum monthly charge, 50c. per hp.

INDUSTRIAL POWER (Customer's option):

Meter rate (for continuous service): $1.50 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as follows:

For first 100 kw-hrs. per month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	3c per kw-hr.
For next 3,500 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

For twenty-hour off-peak service: $1.10 fixed change per kilowatt connected load or maximum demand per month, plus an energy charge as shown above. Less a discount of 10 per cent if paid within 15 days from date of billing. The customer will be required to furnish a time switch for off-peak service.

RURAL DOMESTIC LIGHTING AND POWER:

Meter rate: To apply in the territory adjacent to and outside of the corporate limits:

First 30 kw-hrs. per month	13c. per kw-hr.
Next 60 kw-hrs. per month	11c. per kw-hr.
Next 120 kw-hrs. per month	10c. per kw-hr.
Next 210 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing. Minimum monthly charge for lighting service, $1; minimum monthly charge for power service, $1.

ASHLAND. Population, 910. Ashland municipal light and water department. Number of customers, 160.

STREET LIGHTING:

60 type C Mazda 50-watt lamps, moonlight schedule. Renewals furnished by city. No charge

COMMERCIAL LIGHTING:

Meter rates: Residence: first 20 kw-hrs., 15c.; second 10 kw-hrs., 12.5c.; all in excess of 30 kw-hrs., 10c. Business houses: 10c. per kw-hr.

Flat rates: not to exceed 3 lamps at 75c. each.

Special rates, $2 per hour extra run of plant.

Minimum rate, $1.25. Discounts, none. Meters are owned by consumers.

ASSARIA. Population, 246. (See Gypsum City).

ATCHISON. Population, 16,429. Atchison Railway, Light and Power Company. Lighting circuit, a. c., day and night, 110 v. Motor circuit, a. c., day and night, 220 v., 3-phase. Power, d. c. circuit, 600 v. Number of customers, 2273.

STREET LIGHTING:

112 Magnetite arc 4-amp. lamps, 3200 hours, $6,200 per year total. 200 incandescents, all night moonlight schedule. Renewals are furnished by the company.

COMMERCIAL LIGHTING:

Meter rates:

Rate A.—Residence district: 10c. per kw-hr., with a penalty of 10 per cent added if not paid at the office of the company before the tenth of the month.

Rate B.—Business district: Business house rate, 8c. per kw-hr., with a penalty as above.

Rate C.—Business district: First 30 hours burning of connected load, 10c. per kw-hr. Current consumed in excess of this amount, 5c. per kw-hr. with penalty as above.

Minimum rate of 50c. per month.

COMMERCIAL POWER:

Meter rates:

0 to 25 kw-hrs.	10c. and	$2.50 for all between	26 and 30 kw-hrs.
31 to 50 kw-hrs.	9c. and	4.50 for all between	51 and 60 kw-hrs.
61 to 75 kw-hrs.	8c. and	6.00 for all between	76 and 85 kw-hrs.
86 to 100 kw-hrs.	7c. and	7.00 for all between	101 and 120 kw-hrs.
121 to 200 kw-hrs.	6c. and	12.00 for all between	201 and 240 kw-hrs.
241 to 500 kw-hrs.	5c. and	25.00 for all between	501 and 625 kw-hrs.
626 to 1,000 kw-hrs.	4c. and	40.00 for all between	1,001 and 1,350 kw-hrs.
1,251 to 2,500 kw-hrs.	3c. and	75.00 for all between	2,501 and 3,750 kw-hrs.
3,751 to 4,000 kw-hrs.	2.5c. and	100.00 for all between	4,001 and 5,000 kw-hrs.

For all above 5000 kw-hrs. with guaranteed consumption on time contract, 2.5c. per kw-hr. A penalty of 10 per cent will be added on all bills if not paid before the tenth of the month.

Minimum rate of $1 per month. Company owns all meters and charges no rentals.

AURORA. Population, 269. Furnished by Concordia Electric Light Company.

STREET LIGHTING:

80 c. p. lamps, all-night schedule	$2.00 per month.
80 c. p. lamps, dusk to midnight schedule	1.20 per month.

Sign lighting, 5c. per kw-hr.

COMMERCIAL LIGHTING:

Up to 20 kw-hrs	12c. per kw-hr.
Next 20 kw-hrs	11c. per kw-hr.
Next 20 kw-hrs	10c. per kw-hr.
Next 20 kw-hrs	9c. per kw-hr.
Next 20 kw-hrs	8c. per kw-hr.
All over 100 kw-hrs	7c. per kw-hr.

Minimum, $1.50 per month. No discount.

RESIDENCE LIGHTING: 15c. per kw-hr.

Discount, 10 per cent within five days. Minimum, $1.20 per month.

RURAL SERVICE: 12c. per kw-hr.

Minimum, $2 per month.

POWER SERVICE:

First 50 kw-hrs	10c. per kw-hr.
Next 10 kw-hrs	9c. per kw-hr.
Next 10 kw-hrs	8c. per kw-hr.
Next 10 kw-hrs	7c. per kw-hr.
Next 10 kw-hrs	6c. per kw-hr.
All over 100 kw-hrs	5c. per kw-hr.

Minimum charge, $1 per month or 50c. per hp.

SPECIAL CONTRACTS:

Grain elevator, $8.50 for first 100 kw-hrs.; 4c. per kw-hr. for all additional. Flour mill at Greenleaf, 2½c. per kw-hr.

BALDWIN. Population, 1386. Municipal Light and Water Plant.

LIGHTING AND POWER:

First 10 kw-hrs	10c. per kw-hr.
Next 10 kw-hrs	9c. per kw-hr.
Next 80 kw-hrs	8c. per kw-hr.
Next 200 kw-hrs	7c. per kw-hr.
Next 700 kw-hrs	6c. per kw-hr.

Minimum charge, 50c. per month.

BELLEVILLE. Population, 2224. Municipal Water and Electric Light Plant.

LIGHTING AND POWER:

12c. per kw-hr. per light only or light and power; 8c. per kw-hr. for power only.
Minimum monthly charge, $1. Meters sold at $11.50 for 5-ampere capacity, or $13.00 for 10-ampere capacity, or rented at 25c. per month.

BENTON (BURRTON AND TOWANDA). Population, of Benton, 240.

RESIDENTIAL AND COMMERCIAL LIGHTING:

Meter rate:

First 30 kw-hrs. per month	13c. per kw-hr.
Next 60 kw-hrs. per month	11c. per kw-hr.
Next 120 kw-hrs. per month	10c. per kw-hr.
All over 210 kw-hrs. per month	9c. per kw-hr.

Less 10 per cent discount if paid within fifteen days after date of billing.
Minimum monthly charge, $1.

ADVERTISING LIGHTING:

Flat rate: Consisting of sign, outline, display window and spectacular lighting, burning from dusk until midnight, every night, under power company control: for watt rated capacity of connected load per month, 1c. net.
Minimum monthly charge, $1.

INDUSTRIAL POWER:

Meter rate:

First 100 kw-hrs. per month	9c. per kw-hr.
Next 100 kw-hrs. per month	8c. per kw-hr.
Next 100 kw-hrs. per month	7c. per kw-hr.
Next 200 kw-hrs. per month	6c. per kw-hr.
Next 200 kw-hrs. per month	4c. per kw-hr.
All over 700 kw-hrs. per month	3½c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.
Minimum monthly charge, $1 per hp.

INDUSTRIAL POWER (Customer's option):

For continuous service: $1.50 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as follows:

For first 100 kw-hrs. per month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	3c. per kw-hr.
For next 3,500 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

Twenty-hour off peak service: $1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above. Less a discount of 10 per cent if paid within fifteen days from date of billing. The customer will be required to furnish a time switch for off peak service.

RURAL DOMESTIC LIGHTING AND POWER:

Meter rate: To apply to the territory adjacent to and outside of the corporate limits of Burrton, Benton, and Towanda:

For first 30 kw-hrs. per month	13c. per kw-hr.
For next 60 kw-hrs. per month	11c. per kw-hr.
For next 120 kw-hrs. per month	10c. per kw-hr.
For all over 210 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

Minimum monthly charge for lighting service, $1; minimum monthly charge for power service, $1.

BERN. Population, 450. Bern Electric Light Company. Lighting circuit, a. c., night (mornings in winter), 110 v. Number of customers, 73.

STREET LIGHTING:

3 type C 400-watt lamps, moonlight schedule, $1 per 100 watts; 15 type C 100-watt lamps, moonlight schedule, $1.20 per 100 watts. Renewals furnished by city.

COMMERCIAL LIGHTING RATES:

Meter rate: 15c. per kw-hr.
Flat rate: $2.60 per 100 watts connected.

COMMERCIAL POWER RATE: Meter rate, 10c. per kw-hr.

Minimum rate, $1 for residences, $1.50 for business houses. Meter rent, 25c. per month.

BLUE RAPIDS. Population, 1756. Lighting circuit, a. c., night and day. Number of customers, 200. Rates for year ending December 31, 1915:

STREET LIGHTING:

46 type C Mazda 100-watt lamps, moonlight schedule, $15 per year; 25 type C Mazda 100-watt lamps, moonlight schedule, free.

Franchise calls for 80-watt lamps. Renewals are furnished by company except for free lights which are furnished by the city.

COMMERCIAL LIGHTING:

Meter rates:

First 20 kw-hrs	10c. per kw-hr.
Second 20 kw-hrs	9c. per kw-hr.
Third 20 kw-hrs	8c. per kw-hr.
Fourth 20 kw-hrs	7c. per kw-hr.
Fifth 20 kw-hrs	6c. per kw-hr.

Demand rates:

First 50 kw-hrs	6c. per kw-hr.
Second 50 kw-hrs	5c. per kw-hr.
100 to 500 kw-hrs	4c. per kw-hr.
500 to 1,000 kw-hrs	3c. per kw-hr.

A discount of 10 per cent is given if bills are paid by the tenth of the month.
Flat rate, none.
Minimum rate, 75c.

COMMERCIAL POWER:

Meter rates:

First 50 kw-hrs	6c. per kw-hr.
Second 50 kw-hrs	5c. per kw-hr.
100 to 500 kw-hrs	4c. per kw-hr.
500 to 1,000 kw-hrs	3c. per kw-hr.

Over 1,000 kw-hrs. special rates according to demands load, etc.

SPECIAL RATES:

One contract is for maximum demand of fifteen minutes during the month, $2.50 per kw. with 1c. additional for each kw-hr. used. User building the line.

One contract is for day use, protecting lighting load, at $250 minimum and 1.5c. per kw-hr. User building line, furnishing transformers, etc.

One contract for lighting to an adjacent town at 5c. per kw-hr., company furnishing the line.
An offer has been made to an adjoining town of 4c. per kw-hr., the town to furnish the line.
All rates are based on a water power basis, when the river is high and there is no power, customer furnishes own power on the company's option.
Meters are owned and furnished by the company. Company may charge same to customer as an advancement and remit 5 per cent on light rentals, monthly, until advancement is paid.
This plant now serves Blue Rapids, Waterville, Marysville, and two plaster mills at Blue Rapids.

BUCKLIN. Population, 696. Bucklin Electric Light and Power Company. Number of customers, 150. Rates for the year ending January 1, 1916:

STREET LIGHTING:

126 Mazda 40-watt lamps until 12 p. m., $8 per year. Renewals are furnished by the city.

COMMERCIAL LIGHTING: Meter rate, 10c. per kw-hr.

Flat rate, none.
Minimum rate: Residences, $1.25; business houses, $2.

COMMERCIAL POWER: Meter rate, 8c. per kw-hr.

Meters are owned by customers.

BURLINGAME. Population, 1422. Burlingame Municipal Electric Light Plant. Lighting circuit, night only, 110 v. 60 cycles. Number of customers, 290.

STREET LIGHTING:

100 type C, series 5.5. amp. lamps, moonlight schedule, total flat rate of $1,000 per year. Renewals are furnished by the plant.

COMMERCIAL LIGHTING: Meter rate, 12c. per kw-hr.

Flat rate, none.
Discounts, none.
Minimum rate: 50c. per month including meter rental; 25c. per month where customer owns meter.
Meter rental, 25c. per month. Customers have privilege of buying meters at cost.

BURLINGTON. Population, 2180. Burlington Light, Power and Manufacturing Company. Lighting circuit, a. c., night only. Number of customers, 400.

COMMERCIAL LIGHTING:

Meter rate:

Business Houses.	
First 50 kw-hrs	10c. per kw-hr.
Next 10 kw-hrs	9c. per kw-hr.
Next 10 kw-hrs	8c. per kw-hr.
Next 10 kw-hrs	7c. per kw-hr.
All over this	5c. per kw-hr.
Residences.	
First 20 kw-hrs	12.5c. per kw-hr.
All over 20 kw-hrs	8c. per kw-hr.

Where irons are used:

First 12 kw-hrs	12.5c. per kw-hr.
All over 12 kw-hrs	8c. per kw-hr.

Flat rate: For offices where only one light is used, 50c. per 60-watt lamp.
Minimum rate, $1.

COMMERCIAL POWER: Meter rate, 4c. per kw-hr.

Discounts, none.

BURR OAK. Population, 1132. Furnished by Concordia Light Company.

STREET LIGHTING:

Dusk to midnight schedule, $1.10 per lamp per month.
Sign lighting, 5c. per kw-hr.

COMMERCIAL LIGHTING:

Meter rate:

Business hours:	
First 20 kw-hrs	12c. per kw-hr.
Second 20 kw-hrs	11c. per kw-hr.
Third 20 kw-hrs	10c. per kw-hr.
Fourth 20 kw-hrs	9c. per kw-hr.
Fifth 20 kw-hrs	8c. per kw-hr.
All over 100 kw-hrs	7c. per kw-hr.

Minimum monthly charge, $1.50. No discount.

RESIDENCE LIGHTING: 15c. per kw-hr.

Minimum monthly charge, $1.35. Discount of 10 per cent for payment in five days.

SPECIAL RATE: Rural rate, 12c. per kw-hr.

Minimum, $2 per month.

BURRTON. Population, 689. (See Benton).

CALDWELL. Population, 2205. Caldwell municipal plant. Lighting circuit, a. c., day and night. Rates for year ending December 31, 1916:

STREET LIGHTING:

10 Type C, 6.6 amp. lamps, 250 c. p., moonlight schedule; 50 type C, 6.6 amp. lamps, 100 c. p., moonlight schedule; 124 Mazda 60-watt lamps, moonlight schedule. Total, $150 per month. Renewals furnished by plant.

COMMERCIAL LIGHTING:

Meter rate:

Up to 20 kw-hrs. per month	10c. per kw-hr.
20 to 35 kw-hrs. per month	9c. per kw-hr.
35 to 50 kw-hrs. per month	8c. per kw-hr.
50 to 100 kw-hrs. per month	7c. per kw-hr.
100 and up kw-hrs. per month	6c. per kw-hr.

Flat rate, none.
Minimum rate, 50c. per month.

COMMERCIAL POWER: Same as lighting.

Discount of 10 per cent if bill is paid by tenth of the month.

CANEY. Population, 3597. Caney Electric Light and Railway Company. Lighting circuit, a. c., day and night, 110 v. Motor circuit, a. c., 220 to 110 v. single phase. Number of customers, 221.

STREET LIGHTING:

41 arcs, A and B type, 7.5 amp. lamps, moonlight schedule, $60 each per year. Renewals are furnished by the company.

COMMERCIAL LIGHTING: Meter rates, 10c., 8c., and 7c. per kw-hr.

Flat rates, $1; minimum, 50c. per 60 watts.
Minimum rate, $1.

COMMERCIAL POWER: Meter rate: 7 to 2c. per kw-hr.

Discounts, 1c. per kw-hr. if paid before the tenth of the month.

CAWKER CITY. Population, 870. Electric Light and Power Company. Maximum rate, 20c. per kw-hr. $1 per month minimum charge.

CENTRALIA. Population, 665. Municipal Light and Power Plant. Lighting circuit, a. c., 110 v.; motor circuit, a. c., 220 v. Number of customers, 140.

STREET LIGHTING:

8 Mazda 4 amp., 250-watt lamps, moonlight schedule; 10 type C, 4 amp., 100 c. p. lamps, moonlight schedule; 29 type C, 4 amp., 60 c. p. lamps, moonlight schedule.
Flat rate of $75 per month.
Renewals furnished by the city.

COMMERCIAL LIGHTING:

Meter rates:

0 to 40 kw-hrs	12c. per kw-hr.
41 to 60 kw-hrs	11c. per kw-hr.
61 and over of kw-hrs	10c. per kw-hr.

Flat rate, none. Minimum rate, $1 per month.

COMMERCIAL POWER:

Meter rates:

0 to 100 kw-hrs	6c. per kw-hr.
101 to 500 kw-hrs	5c. per kw-hr.
101 to 500 kw-hrs	5c. per kw-hr.
501 to 1,000 kw-hrs	4.5c. per kw-hr.
1,000 and over of kw-hrs	4c. per kw-hr.

Minimum rate, $3 per month for 5 hp. and over.
Meter rent, 10c. per month.
Special rates: Current is supplied to Corning and to Goff, delivered to the transformer station at 5.71c. per kw-hr. Corning has 80 consumers and 33 street lights. Goff has 60 consumers and 30 street lights.

CHANUTE. Population, 9272. Municipal Electric Light Plant. Circuits: Day and night lighting circuit, 110 v., a. c., single phase; day and night motor circuit, 110 to 220 v., a. c., single phase. Number of customers, 750. Rates for year ending February 1, 1916:

STREET LIGHTING:

165 Type C, 250 c. p. lamps. City levies ½ mill tax for this purpose, which nets about $3,000 per year.

COMMERCIAL LIGHTING:

Meter rates:

1 to 25 kw-hrs	8c. per kw-hr.
25 to 50 kw-hrs	7c. per kw-hr.
50 to 100 kw-hrs	6c. per kw-hr.
100 to 200 kw-hrs	5c. per kw-hr.
200 and over of kw-hrs	4c. per kw-hr.

Minimum rate, 50c. per month.
Flat rate, none.

COMMERCIAL POWER:

Meter rate: Up to ½ hp., lighting rate; ½ hp. and up, 2c. per kw-hr.
Minimum rate, 25c. per month per hp.
Meters are rented to customers or a deposit of $5.00 is made for the entire time used, the money to be refunded when the meter is returned.

CHAPMAN. Population, 781. Electrical Department of the City of Chapman. Power is purchased from the Union Electric Company of the city of Abilene. Number of customers, 135.

STREET LIGHTING:

Meter rates:

First 5 kw-hrs. consumed	12c. per kw-hr.
Next 5 kw-hrs. consumed	11c. per kw-hr.
Next 10 kw-hrs. consumed	10c. per kw-hr.
Next 10 kw-hrs. consumed	9c. per kw-hr.
Next 20 kw-hrs. consumed	8c. per kw-hr.
All over 50 kw-hrs. consumed	7c. per-kw-hr.

Flat rate, none.
Minimum rate, 60c. per month.

COMMERCIAL POWER:

The minimum charge for power and heating where the connected load is 900 to 9000 watts, inclusive, is 50c. per 1,000 watts connected load. 1,000 watts for each hp.

Meter rates:

First 20 kw-hrs. consumed	7c. per kw-hr.
Next 20 kw-hrs. consumed	6.5c. per kw-hr.
Next 20 kw-hrs. consumed	6.0c. per kw-hr.
Next 20 kw-hrs. consumed	5.5c. per kw-hr.
All over 80 kw-hrs. consumed	5.0c. per kw-hr.

Special rates: For all motors of 12 hp. and over a minimum of $1 per hp. per month is charged and current rate is 5c. per kw-hr. per month.
Meters: Customers own meters. If city provides meter the customer pays $12.50 guarantee and 15c. per month rent for the meter. Guarantee to be refunded when customer quits using energy.

CHEROKEE. Population, 1452. (See Pittsburg).

CHERRYVALE. Population, 4304.

RESIDENTIAL AND COMMERCIAL LIGHTING:

Meter rate: First 60 kw-hrs., per kilowatt of connected load per month, 10c. per kw-hr. For all current in excess of the first 60 kw-hrs. per kilowatt connected load per month, 6c. per kw-hr.
Minimum connected load to which 6c. rate applies, 200 watts.
Minimum monthly charge, $1.
In computing size of connected load for billing purposes, 100 per cent of the actual connected load between 0 and 2.5 kilowatts will be considered active; 75 per cent of the actual connected load between 2.5 and 5 kilowatts will be considered active, and 50 per cent of the actual connected load over 5 kilowatts will be considered active.

ADVERTISING LIGHTING:

Flat rate: Consisting of sign, outline, display window and spectacular lighting, burning from dusk until midnight, every night, under power company control: per watt rated capacity of connected load per month, 1c. net.
Minimum monthly charge, $1.

INDUSTRIAL POWER—(Customer's option):

Meter rate:

For first 100 kw-hrs. per month	8c. per kw-hr., net.
For next 100 kw-hrs. per month	6c. per kw-hr., net.
For next 100 kw-hrs. per month	5c. per kw-hr., net.
For next 200 kw-hrs. per month	4c. per kw-hr., net.
For next 1,000 kw-hrs. per month	3½c. per kw-hr., net.
For next 3,500 kw-hrs. per month	3c. per kw-hr., net.
All over 5,000 kw-hrs. per month	2½c. per kw-hr., net.

Minimum monthly charge, $1.

INDUSTRIAL POWER—(Customer's option):

Meter rate for continuous service:

For first 100 kw-hrs. per month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

For twenty-hour off-peak service: $1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above. Less a discount of 10 per cent if paid within fifteen days from date of billing. The customer will be required to furnish a time switch for off-peak service.

CLAFLIN. Population, 554. Claflin Telephone, Light and Garage Company. Lighting circuit, day and night light and motor circuit, 110 v. Number of customers, 114.

STREET LIGHTING:

37 Mazda 100-watt lamps, till 12 p. m., schedule, $660 per year.
Renewals are furnished by the light company.

COMMERCIAL LIGHTING:

Meter rate:

First 20 kw-hrs	15c. per kw-hr.
Next 50 kw-hrs	10c. per kw-hr.
All over 70 kw-hrs	7c. per kw-hr.

Flat rate, 1c per watt connected load.

Minimum rate, $1.25. Discounts, none.

Meters: A $10 deposit is required which is refunded on discontinuation of service, or meter may be rented at 25c. per month.

CLAY CENTER. Population, 4000. Municipal Light and Water Plant. Circuits: a. c., day and night lighting circuit, 110 v.; a. c., day and night motor circuits, 220 v., 3 phase. Number of customers, 903.

STREET LIGHTING:

115 Type C, 6.6. amp. lamps, 60-watt, moonlight, all night schedule; 50 5-light posts, 110 v. Mazdas, 40 and 60-watt lamps, all night schedule.

Flat rate of 3.7 c. per kw-hr.

Renewals are furnished by plant.

COMMERCIAL LIGHTING:

Meter rates:

Business houses	8.5c. per kw-hr.
Residences	10.0c. per kw-hr.

Discount of 10 per cent for prompt payment.

Minimum rate: Residence, 75c., $1 and $1.50 on 6, 12 and 18 lights, respectively.

COMMERCIAL POWER:

Meter rate: 5c. per kw-hr. net, with a minimum of $1.50 per month.

CLIFTON. Population, 614. (See Aurora).

CLYDE. Population, 1057. (See Aurora).

COFFEYVILLE. Population, 12,678. Municipal Water and Light Department. Circuits: lighting, day and night, 115 v. Motor, day and night, 220 v.

STREET LIGHTING:

140 a. c. series arcs, 6.6. amp. lamps, $36 per year; 140 posts, one 100-watt, 4 60-watt lamps, moonlight schedule, $18 per post per year.

Schedule of rates:

First 60 hours per month of total rated load	5c. per kw-hr.
Next 60 hours per month of total rated load	3c. per kw-hr.
All additional per month of total rated load	1c. per kw-hr.

Minimum shall be 50c. per month per kw. of total connected load.

These rates apply to consumers making full meter deposit. No installation shall be considered at less than one kilowatt rated load. All lighting shall come under class A service and shall be rated at the total connected load. Motors used generally during the day time shall come under class B service and shall be rated at half connected load. Motors not used during the peak load shall come under class C service and shall be rated at one-fourth connected load. The peak hours during which class C service cannot be used shall be from 5 to 9 p. m., during the months of November, December, January, February; from 6 to 10 p. m., during March, April, September and October, and from 7 to 11 p. m., during May, June, July and August.

COLDWATER. Population, 684. Municipal Water and Light Department.

LIGHTING RATES:

First 20 kw-hrs	15c. per kw-hr.
Next 10 kw-hrs	12.5c. per kw-hr.
All in excess of 30 kw-hrs	10c. per kw-hr.

POWER RATES: 10c. per kw-hr. for all motor service.

Minimum monthly charge, $1.

COLUMBUS. Population, 3064. The Empire District Electric Company. Maximum rate of 12.5c per kw-hr. $1 per month minimum charge.

CONCORDIA. Population, 4415. Concordia Electric Light Company.

STREET LIGHTING:

250-watt lamps, moonlight after midnight schedule	$4.50 per month.
100-watt lamps	1.80 per month.
75-watt lamps	1.35 per month.

COMMERCIAL LIGHTING:

First 20 kw-hrs	11c. per kw-hr.
Next 20 kw-hrs	10c. per kw-hr.
Next 20 kw-hrs	9c. per kw-hr.
Next 20 kw-hrs	8c. per kw-hr.
Next 20 kw-hrs	7c. per kw-hr.
Second 100 kw-hrs	6c. per kw-hr.
All over 200 kw-hrs	5c. per kw-hr.

Minimum, $1.50 per month. No discount.

INDUSTRIAL POWER:

First 50 kw-hrs	10c. per kw-hr.
Next 10 kw-hrs	9c. per kw-hr.
Next 10 kw-hrs	9c. per kw-hr.
Next 10 kw-hrs	8c. per kw-hr.
Next 10 kw-hrs	7c. per kw-hr.
Next 10 kw-hrs	6c. per kw-hr.
Next 10 kw-hrs	5c. per kw-hr.
All over 100 kw-hrs	5c. per kw-hr.

Minimum charge, $2 or 50c., per hp. per month. No discount.

ADVERTISING: Sign lighting, 5c. per kw-hr.

SPECIAL CONTRACTS: Laundry, 4.5c. per kw-hr.; refrigeration, 3c. per kw-hr.; elevator, $8.50 for 100 kw-hrs.; all over 100 kw-hrs., 4c. per kw-hr.; flour mill, 26c. per kw-hr.

RURAL: 12c. per kw-hr.

Minimum, $2 per month.

RESIDENCE LIGHTING: 15c per kw-hr.

Minimum, $1.20 per month. Discount of 10 per cent for payment within five days.

COTTONWOOD FALLS. Population, 895. The Home Light and Power Company. Circuits: Lighting, a. c., day and night, 110 v. 60 cycles; motors, a. c., day and night, 110 to 220 v., 3 phase, 60 cycles. Supplies power to Strong City also.

STREET LIGHTING:

14 series arcs, 6.6. amp. lamps, moonlight, all-night schedule	$5.00 per month.
54 series arcs, 60 c. p., moonlight, all-night schedule	1.75 per month.

COMMERCIAL RATES:

Meter rate:

First 100 kw-hrs. per month	12.5c. per kw-hr.
101 to 200 kw-hrs. per month	10c. per kw-hr.
201 to 300 kw-hrs. per month	9c. per kw-hr.
301 to 400 kw-hrs. per month	8c. per kw-hr.
401 to 500 kw-hrs. per month	7c. per kw-hr.
500 and over of kw-hrs. per month	6c. per kw-hr.

Minimum rate, none.
Flat rate (see residence rate).

POWER RATES:

Fractional hp. motors, 10c. per kw-hr.
One to twenty hp. motors:

0 to 100 kw-hrs. per month	8c. per kw-hr.
101 to 200 kw-hrs. per month	7c. per kw-hr.
201 to 300 kw-hrs. per month	6c. per kw-hr.
301 and over	5c. per kw-hr.

RESIDENCE RATES:

Meter rate: 12.5 c. per kw-hr.; 10c. per kw-hr., monthly consumption of 100 kw-hrs. or over.
Minimum rate, none.

Flat rate: 1c. per watt per month for lamps installed. (This is an old rate provided for in the franchise and no new contracts have been made since April, 1913.)

COUNCIL GROVE. Population, 2575. Council Grove Ice, Light and Power Company. Circuits: a. c., day and night lighting, 110 v., 60 cycles; a. c., day and night motor, 110 to 220 v., 1 or 3 phase. Number of customers, 475.

STREET LIGHTING:

86 series 6.6 amp., 80 c. p. lamps, all-night schedule, $28 per lamp per year.
Renewals furnished by the company.

COMMERCIAL LIGHTING:

Meter rate:

First 40 kw-hrs	14c. per kw-hr.
Second 40 kw-hrs	12c. per kw-hr.
Third 40 kw-hrs	10c. per kw-hr.
Next 120 kw-hrs	8c. per kw-hr.
All over 240 kw-hrs	6c. per kw-hr.

Subject to a discount of 2c. per kw-hr. for the first 40 kw-hrs. if paid at the company's office by the tenth of the month, provided the minimum bill shall not be less than $1 per month for each meter connected.

Flat rates, none.

COMMERCIAL POWER: 4 and 5c. per kw-hr.

COURTLAND. Population, 454. (See Burr Oak).

DODGE CITY. Population, 3124. Midland Water, Light and Ice Company. Maximum rate, 12½c per kw-hr. Minimum monthly charge, $1.

DOWNS. Population, 1427. Downs Electric Light and Power Company. Maximum rate, 15c per kw-hr.

EL DORADO. Population, 3129. Furnished with power from the Wichita Kansas Gas and Electric Company. a. c. lighting circuit, 110 volts; motor circuit, 220.

RESIDENCE LIGHTING RATE:

First 40 kw-hrs. per month	12c. per kw-hr.
Next 60 kw-hrs. per month	10c. per kw-hr.
Next 100 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent for payment on or before due date stamped on the face of the bill.
Minimum monthly charge, 75c.

BUSINESS LIGHTING RATE:

12c. per kw-hr. when bill is under	$10.00.
10c. per kw-hr. when bill is over	10.00.
9c. per kw-hr. when bill is over	15.00.
8c. per kw-hr. when bill is over	20.00.

Minimum monthly charge, 75c.
Discount of 10 per cent if paid on or before the due date stamped on face of bill.

ADVERTISING RATE:

Flat rate, consisting of sign, outline, display window and spectacular lighting, burning from dusk until midnight every night, under power company control: per watt rated capacity of connected load per month, 1c. net; where lamp renewals are furnished, additional, 4c.
Minimum monthly charge, $1.

POWER RATE:

1 to 10 kw-hrs. per month	12c. per kw-hr.
11 to 20 kw-hrs. per month	10c. per kw-hr.
21 to 40 kw-hrs. per month	9c. per kw-hr.
41 to 60 kw-hrs. per month	8c. per kw-hr.
61 to 100 kw-hrs. per month	7c. per kw-hr.
101 to 150 kw-hrs. per month	6½c. per kw-hr.
151 to 200 kw-hrs. per month	6c. per kw-hr.
201 to 250 kw-hrs. per month	5½c. per kw-hr.
250 to 300 kw-hrs. per month	5c. per kw-hr.
301 to 400 kw-hrs. per month	4½c. per kw-hr.
401 to 500 kw-hrs. per month	4c. per kw-hr.
500 and over of kw-hrs. per month	3c. per kw-hr.

Minimum monthly charge, 50c. per hp.

INDUSTRIAL POWER:

Meter rate, customer's option:

First 100 kw-hrs. per month	8c. per kw-hr.
Next 100 kw-hrs. per month	6c. per kw-hr.
Next 100 kw-hrs. per month	5c. per kw-hr.
Next 200 kw-hrs. per month	4c. per kw-hr.
Next 1,000 kw-hrs. per month	3½c. per kw-hr.
Next 3,500 kw-hrs. per month	3c. per kw-hr.
Over 5,000 kw-hrs. per month	2½c. per kw-hr.

Monthly minimum, 50c. per hp.
Customer's option for continuous service: $1.50 fixed charge per kw. connected load or maximum demand per month plus an energy charge as follows:

First 100 kw-hrs. per month	7c. per kw-hr.
Next 100 kw-hrs. per month	6c. per kw-hr.
Next 100 kw-hrs. per month	5c. per kw-hr.
Next 200 kw-hrs. per month	4c. per kw-hr.
Next 1,000 kw-hrs. per month	3c. per kw-hr.
Next 3,500 kw-hrs. per month	2c. per kw-hr.
Next 10,000 kw-hrs. per month	1c. per kw-hr.
Next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days of date of billing.
For twenty-hour off-peak service: $1.10 fixed charge kw. connected load or maximum demand per month, plus charges as shown above.
Less a discount of 10 per cent if paid within fifteen days of date of billing.
Customer will be required to furnish a time switch for off-peak service.

RURAL DOMESTIC LIGHTING AND POWER:

Meter rate:

First 30 kw-hrs. per month	13c. per kw-hr.
Next 60 kw-hrs. per month	11c. per kw-hr.
Next 120 kw-hrs. per month	10c. per kw-hr.
All over 210 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days of date of billing.
Monthly minimum for lighting, $1; monthly minimum for power, $1.

ELLINWOOD. Municipal light and water plant. Number of customers, 200.

STREET LIGHTING:

20 series enclosed arcs, 6.6 amps., moonlight schedule, $1,200 per year; 6 series Mazda, 6.6 amps., moonlight schedule, $200 per year.

COMMERCIAL LIGHTING RATES:

Meter rates:

First 25 kw-hrs	15c. per kw-hr.
Next 25 kw-hrs	11c. per kw-hr.
All over 50 kw-hrs	10c. per kw-hr.

Minimum, $1 per month.
Customers own meters. Five per cent discount allowed if bill is paid on or before the tenth of the month in which the bill is due.

POWER RATES:

Meter rates:

First 100 kw-hrs	6c. per kw-hr.
Next 50 kw-hrs	5c. per kw-hr.
Next 150 kw-hrs	4c. per kw-hr.
All over 300 kw-hrs	3½c. per kw-hr.

No discount on power rates. Minimum, $1. per month.

ELLIS. Population, 1405. Municipal light and water plant. Lighting, 110 v.; power, 220 v.

STREET LIGHTING RATES:

58 5.5 amps., series Mazda lamps, moonlight schedule, $30 per lamp per year.

LIGHTING AND POWER RATES:

1 to 20 kw-hrs. per month	15c. per kw-hr.
20 to 100 kw-hrs. per month	12½c. per kw-hr.
100 and over of kw-hrs. per month	10c. per kw-hr.

Minimum monthly charge, $1.
There are no flat rates. The customer has the privilege of buying a meter or paying 25c. per month rental.

ELLSWORTH. Population, 2100. People's Light and Ice Plant. Number of customers, 300.

POWER AND LIGHTING RATES:

Meter rates only, monthly:

First 25 kw-hrs	12½c. per kw-hr.
Next 20 kw-hrs	10c. per kw-hr.
Next 56 kw-hrs	7½c. per kw-hr.
Next 200 kw-hrs	6½c. per kw-hr.
All over 300 kw-hrs	5½c. per kw-hr.

STREET LIGHTING:

These are monthly charges: 40 c. p., $1.12; 60 c. p., $1.54; 80 c. p., $1.83; 100 c. p., $2.14. These rates include the lamps and renewals.

EMPORIA. Population, 9100. Kansas Electric Utilities Company.

LIGHTING RATES:

1 to 50 kw-hrs. per month	10c. per kw-hr.
51 to 100 kw-hrs. per month	9c. per kw-hr.
101 to 500 kw-hrs. per month	8c. per kw-hr.
501 to 1000 kw-hrs. per month	6c. per kw-hr.

All over is also 6c. per kw-hr.
Monthly minimum charge, $1.
Discount of 10 per cent if paid on or before the tenth of the month.

POWER RATES:

First 100 kw-hrs. per month	7c. per kw-hr.
Next 100 kw-hrs. per month	6c. per kw-hr.
200 to 1,500 kw-hrs. per month	5c. per kw-hr.

All over 1,501 is 5c. per kw-hr. with a discount of 10 per cent.

Minimum rate on motors, $1 per hp. or less per month; 50c. per month for each additional hp. up to 5. All over 5 hp. 25c. per hp. per month.

ERIE. Population, 1300. Municipal Light and Water Plant. Maximum rate, 8c per kw-hr.

EUREKA. Population, 2333. Eureka Electric and Ice Company. Maximum rate, 12c per kw-hr.

FORMOSO. Population, 453. (See Burr Oak).

FORT RILEY. Population, 1000. (See Junction City).

FORT SCOTT. Population, 10,500. Fort Scott Gas and Electric Company. Number of customers, 740.

STREET LIGHTING:

155 series magnatite arc lamps, 4 amp., 350 watts, dark till dawn schedule, $60 per year each. Lamp renewals furnished by company.

COMMERCIAL LIGHTING RATE:

First 1½ hours use per day of installed capacity, at 12½c. per kw-hr; 80 per cent—10c. per kw-hr., net.

Next 1½ hours use per day of installed capacity at 7½c. per kw-hr.; 80 per cent—6c. per kw-hr., net.

Next 6 hours use per day of installed capacity at 5c. per kw-hr.; 80 per cent—4c. per kw-hr., net.

All use in excess of 9 hours per day of installed capacity at 2½c. per kw-hr.; 80 per cent—2c. per kw-hr., net.

POWER RATE:

First 1 hour use per day of installed capacity at 8c. per kw-hr., less 20 per cent—6.4c. per kw-hr., net.

Next 1 hour use per day of installed capacity at 6c. per kw-hr., less 20 per cent—4.8c. per kw-hr., net.

Next 4 hours use per day of installed capacity at 4c. per kw-hr., less 20 per cent—3.2c. per kw-hr., net.

All use in excess of 6 hours per day of installed capacity, 2c. per kw-hr., less 20 per cent—1.6c. per kw-h r., net.

RESIDENCE RATE:

First 25 kw-hrs. per month at 15c. per kw-hr., less 20 per cent—12c. per kw-hr. net.

All use in excess of 25 kw-hrs. in any one month at 7½c. per kw-hr., less 20 per cent—6c. per kw-hr., net.

The 20 per cent discount is conditional on prompt payments of bills on or before the tenth of the month.

No installation will be figured at less than 1 kw. Outside sign or decoration lighting or fans need not be included in arriving at installed capacity.

Theaters and picture shows may be figured on the basis of 75 per cent of the total installed capacity.

POWER CAPACITY.

No installation to be figured as less than one kw. Where installations are less than 7½ kw. the total capacity of the service installed is to be figured.

Between 7½ and 15 kw. the installed capacity may be figured as 75 per cent of the total connected service but not to be less than 7½ kw.

Minimum charge on power is 75c. per hp. per month. Minimum charge on commercial light to be 5c. per 16. c. p. lamps or 50-watt equivalent connected, but not less than $1 per month.
Minimum charge on residences to be $1 per month.

FRANKFORT. Population, 1450. Frankfort Light and Power Company.

STREET LIGHTING:

50 series, 6.6 amp. lamps, 60 c. p.	$24 each per year.
4 arcs	80 each per year.

Renewals by company.

RATES FOR PRIVATE CONSUMERS:

To and including 10 kw-hrs. per month	15c. per kw-hr.
Over 10 and not more than 20 kw-hrs. per month	14c. per kw-hr.
Over 20 and not more than 40 kw-hrs. per month	13c. per kw-hr.
Over 40 and not more than 70 kw-hrs. per month	12c. per kw-hr.
Over 70 and not more than 100 kw-hrs. per month	10c. per kw-hr.
Over 100 kw-hrs. per month	9c. per kw-hr.

ELECTRICITY FOR ALL PURPOSES OTHER THAN LIGHTING:

Up to an including 80 kw-hrs. per month	10c. per kw-hr.
Over 80 and up to and including 250 kw-hrs. per month	8c. per kw-hr.
Over 250 and up to and including 350 kw-hrs. per month	6c. per kw-hr.
Over 350 kw-hrs. per month	4½c. per kw-hr.

Minimum rate to private consumers where light company installs and maintains the meter shall be 75c. per month.

Private consumers may own their own meter but minimum of 75c. is still charged.

FREDONIA. Population, 3100. Fredonia Ice and Light Company. Number of customers, 285.

STREET LIGHTING:

78 series incandescent lamps, 6.6 amp., 100 c. p., moonlight schedule, $1.66 2-3 per lamp per month. Renewals by the company.

DOMESTIC RATE:

First 25 kw-hrs	10c. per kw-hr.
Next 25 kw-hrs	8c. per kw-hr.
All over 50 kw-hrs	6c. per kw-hr.

Discount of 10 per cent allowed if paid before the tenth of the month.

COMMERCIAL RATES:

6c. per kw-hr. straight; for motor load, day use only, 4c. per kw-hr. Discount of 5 per cent on this rate if paid before the tenth of the month.

FRONTENAC. Population, 3396. (See Pittsburg).

GARDEN CITY. Population, 3500.

GARDEN CITY TELEPHONE, LIGHT AND MANUFACTURING COMPANY. Number of customers, 220. No street lighting.

LIGHTING:

Meter rates:

1 to 50 kw-hrs. per month.................................... 6c. per kw-hr.
All above 50 kw-hrs. per month............................ 5c. per kw-hr.

Minimum is 50c per month.
The company owns all meters and furnishes them free of charge.
Flat rate: 25c. per lamp per month.

POWER RATES:

1 to 50 kw-hrs. per month.................................... 4c. per kw-hr.
All above 50 kw-hrs. per month............................ 3c. per kw-hr.

Minimum power rate is $1 for first hp. connected load and 25c. for each additional hp.
Discount of 1c. per kw. if paid by the fifteenth of the month.

MUNICIPAL LIGHT, POWER AND WATER COMPANY. Number of customers, 509.

STREET LIGHTING RATES:

130 series C Mazda lamps, 6.6 amp., all-night schedule and 150 multiple Mazda lamps, 60 and 100 watts, dusk to midnight schedule, paid by tax of .8 mill on $3,000,000.

COMMERCIAL LIGHTING RATES:

First 50 kw-hrs. per month.................................. 7c. per kw-hr.
All over 50 kw-hrs. per month............................. 6c. per kw-hr.

All energy is billed at 8c. if paid after the tenth.
Minimum rate, 75c. per month. City owns all meters and makes no charge for them.
Flat rate:

1 40-watt lamp.. 40c. per month.
1 60-watt lamp.. 60c. per month.

A discount of 2c. per kw-hr. is paid for all over 50 kw-hrs. per month if paid before the tenth.

POWER RATES:

First 100 kw-hrs., 3½c. per kw-hr.; over that, 2½c. per kw-hr. The minimum is $1 for the first hp. per month and 25c. for each additional hp.

If a motor does not run enough to use the minimum, the rate is a flat rate equal to the minimum.

There is also a cooking rate of 3c. per kw-hr.

These rates are the results of competition between the private plant and the municipal plant. The private plant has been operating for several years. The municipal plant was built in 1914.

GARNETT. Population, 2334. Municipal plant. Number of customers, 200.

STREET LIGHTING:

75 6.6 amp. lamps, moonlight schedule. No charge.

COMMERCIAL LIGHTING:

First 20 kw-hrs..10c. per kw-hr.
Next 20 kw-hrs... 9c. per kw-hr.
Next 20 kw-hrs... 8c. per kw-hr.
Next 20 kw-hrs... 7c. per kw-hr.
Next 20 kw-hrs... 6c. per kw-hr.
All in excess of above..................................... 5c. per kw-hr.

Minimum charge of 75c. per month.

COMMERCIAL POWER: As low as 4c. per kw-hr.

GLASCO. Population, 750. Municipal Electric Light Company. Energy is purchased from Concordia. Number of customers, 150.

LIGHTING RATES:

1 to 20 kw-hrs... 18c. per kw-hr.
21 to 40 kw-hrs.. 15c. per kw-hr.
41 and over of kw-hrs..................................... 12c. per kw-hr.

Discount of 16 2-3 per cent if paid by the tenth. Minimum rate, $1.20. Power rate, 10c. straight. No street lighting rates.

GOODLAND. Population, 1990. Goodland Light and Power Company. Number of customers, 315.

STREET LIGHTING:

167 series Mazda lamps, 6.6 amp., 40 c. p., all night schedule, $1.25 per month. Lamps are renewed by the company.

The lighting and power rates as obtained from this company were given merely as 6c. to 10c. per kw-hr. The minimum is $1 per month. A deposit of $10 is made when a meter is installed and is refunded whenever the meter is taken out.

GIRARD. Population, 2500. Municipal Electric Light and Water Company. Number of customers, 585.

STREET LIGHTING:

150 C type lamps, 6.6 amp., moonlight schedule, paid by tax.

COMMERCIAL RATE:

First 25 kw-hrs. per month	10c. per kw-hr.
Next 25 kw-hrs. per month	8c. per kw-hr.
All over 50 kw-hrs. per month	6c. per kw-hr.

Minimum rate of $1 per month. Meter rent 10c. per month.

POWER RATES:

These were given only as 2, 2½, and 4c. per kw-hr. A set rate of $1 per month per hp. is a minimum.

GREAT BEND. Population, 4660. Great Bend Water and Electric Company.

STREET LIGHTING:

109 series lamps, 6.6 amp., 42 watts, moonlight schedule, $10.80 per year; 9 series lamps, 6.6 amp., 375 watts, moonlight schedule, $96 per year. Renewals by the company.

RESIDENCE RATES:

First 90 hours of 50 per cent of connected load	11c. per kw-hr.
All in excess thereof	6c. per kw-hr.

COMMERCIAL RATES:

First 90 hours use of full connected load	11c. per kw-hr.
Next 60 hours use of full connected load	9c. per kw-hr.
Next 60 hours use of full connected load	7c. per kw-hr.
All in excess thereof	5c. per kw-hr.

POWER RATES:

These apply to installations of 3 hp. or over:

First 60 hours use of connected load	7¼c. per kw-hr.
Next 30 hours use of connected load	7c. per kw-hr.
Next 30 hours use of connected load	6¾c. per kw-hr.
All in excess thereof	6½c. per kw-hr.

Minimum charge, 75c. per month. Minimum of $1 per hp. of motors. Discount of 1c. per kw-hr. if bills are paid before the tenth of the month.

GREENLEAF. Population, 781. (See Aurora).

GYPSUM. Population, 625. Gypsum Light and Power Company. This company includes Assaria also.

STREET LIGHTING. (Both towns.)

64 80 c. p. lamps, midnight schedule, $20 per year per 100 c. p.
Lamp renewals by company.

COMMERCIAL LIGHTING RATES:

First 10 kw-hrs	16 2-3c. per kw-hr.
Next 20 kw-hrs	11c per kw-hr.
Balance	8 1-3c. per kw-hr.

RESIDENCE LIGHTING RATES:

First 15 kw-hrs	16 2-3c. per kw-hr.
Balance	11c. per kw-hr.

POWER RATES:

First 400 kw-hrs	5c. per kw-hr.
Next 200 kw-hrs	4½c. per kw-hr.
Next 200 kw-hrs	4c. per kw-hr.
Next 200 kw-hrs	3½c. per kw-hr.
Balance	3c. per kw-hr.

For residence lighting, customers where they have not less than 500 watts of cooking appliances and pay a double minimum amounting to $2.50 per month, the following rate is given which applies to all energy consumed.

First 10 kw-hrs. used	16 2-3c. per kw-hr.
Balance	4.4c. per kw-hr.

This rate takes a 10 per cent discount. Ten per cent discount on all bills paid by the tenth of the month.

Minimum, $1.25 for metered service; 60c. for demand service, net. No meter rental.

HANOVER. Population, 1000. Municipal Electric Light Company. Energy is purchased from Hanover Milling Company, at 4½c at the switchboard.

STREET LIGHTING:

37 250 c. p. lamps, at no special time and paid for by city.

LIGHTING RATES:

12c. per kw-hr. to $5.

Bills of $5 to $10	10 per cent discount.
Bills of 10 to 15	20 per cent discount.
Bills of 15 to 20	25 per cent discount.
Bills of 20 and over	33 1-3 per cent discount.

Minimum, 30c. per month. Meter rental, 20c. per month.

POWER RATES:

10c. per kw-hr. up to $4.

Bills of $4 to $7	10 per cent discount.
Bills of 7 to 10	20 per cent discount.
Bills of 10 to 15	30 per cent discount.
Bills of 15 to 30	40 per cent discount.
Bills of 30 and over	45 per cent discount.

Meter rental, 20c. per month.
Minimum rate, $1 per connected hp. per month.

HALSTEAD. Population, 1004.

RESIDENTIAL AND COMMERCIAL LIGHTING:

First 30 kw-hrs. per month	13c. per kw-hr.
Next 60 kw-hrs. per month	11c. per kw-hr.
Next 120 kw-hrs. per month	10c. per kw-hr.
All over 210 kw-hrs. per month	9c. per kw-hr.

Less 10 per cent discount if paid within fifteen days after date of billing.
Minimum monthly charge, $1.

ADVERTISING LIGHTING. (Flat rate.)

Consisting of sign, outline, display window and spectacular lighting. Burning from dusk until midnight, every night, under power company's control.
Per watt rated capacity of connected load per month, 1c. net.
Minimum monthly charge, $1.

INDUSTRIAL POWER:

Meter rate:

First 100 kw-hrs. per month	9c. per kw-hr.
Next 100 kw-hrs. per month	8c. per kw-hr.
Next 100 kw-hrs. per month	7c. per kw-hr.
Next 200 kw-hrs. per month	6c. per kw-hr.
Next 200 kw-hrs. per month	4c. per kw-hr.
All over 700 kw-hrs. per month	3½c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.
Minimum monthly charge, $1 per hp.

INDUSTRIAL POWER. (Customer's option):

For continuous service:
$1.50 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as follows:

For first 100 kw-hrs. pr month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	3c. per kw-hr.
For next 3,500 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.
For twenty-hour off-peak service:
$1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above.
Less a discount of 10 per cent if paid within fifteen days from date of billing.
The customer will be required to furnish a time switch for off-peak service.

RURAL DOMESTIC LIGHTING AND POWER:

Meter rate:

For first 30 kw-hrs. per month	13c. per kw-hr.
For next 60 kw-hrs. per month	11c. per kw-hr.
For next 120 kw-hrs. per month	10c. per kw-hr.
All over 210 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

Minimum monthly charge for lighting service	$1.
Minimum monthly charge for power service	$1.

HERINGTON. Population, 3275. Municipal Water and Light Plant.

STREET, RESIDENCE AND COMMERCIAL LIGHTING:

First 30 kw-hrs	12c. per kw-hr.
Next 30 kw-hrs	10c. per kw-hr.
Next 30 kw-hrs	8c. per kw-hr.
Balance	6c. per kw-hr.

MOTOR RATES:

5c. per kw-hr. When using more than $10 per month, 4c. per kw-hr.

HIAWATHA. Population, 3000.

HIAWATHA LIGHT, POWER AND ICE COMPANY. No street lighting.

LIGHTING RATES:

12½c. per kw-hr. with discounts.

Bills of $10	10 per cent discount.
Bills of $20	15 per cent discount.
Bills of $30	20 per cent discount.
Bills of $40	25 per cent discount.
Bills of $50	30 per cent discount.

Minimum, $1. Company owns all meters and charges no rental.

POWER RATES:

100 kw-hrs. and under	9c. per kw-hr.
150 kw-hrs. and under	8½c. per kw-hr.
200 kw-hrs. and under	8c. per kw-hr.
250 kw-hrs. and under	7½c. per kw-hr.
300 kw-hrs. and under	7c. per kw-hr.
350 kw-hrs. and under	6½c. per kw-hr.
400 kw-hrs. and under	6c. per kw-hr.
450 kw-hrs. and under	5½c. per kw-hr.
500 kw-hrs. and over	5c. per kw-hr.

MUNICIPAL WATER AND LIGHT COMPANY.

STREET LIGHTING ONLY:

Operating expenses are paid out of general fund no rates being charged for street lights.

HIGHLAND. Population, 763. Home Telephone and Electric Company. Maximum rate, 15c per kw-hr. Minimum monthly charge, $1.25.

HOISINGTON. Population, 1975. Hoisington Electric and Ice Company. Supplied with energy from Great Bend Water and Electric Company.

STREET LIGHTING:

59 series lamps 6.6 amp., 42 watts, all-night schedule	$15.50 per year.
12 series lamps 6.6 amp., 160 watts, all-night schedule	$38.40 per year.
30 series lamps 6.6 amp., 160 watts, midnight schedule	$28.30 per year.

RESIDENCE LIGHTING:

First 90 hours use of 50 per cent of connected load	11c. per kw-hr.
All in excess thereof	6c. per kw-hr.

COMMERCIAL LIGHTING:

First 90 hours use of full connected load	11c. per kw-hr.
Next 60 hours use of full connected load	9c. per kw-hr.
Next 60 hours use of full connected load	7c. per kw-hr.
All in excess thereof	5c. per kw-hr.

POWER RATE:

Apply to installations of 3 hp. or over.

First 60 hours use of connected load	7¼c. per kw-hr.
Next 30 hours use of connected load	7c. per kw-hr.
Next 30 hours use of connected load	6¾c. per kw-hr.
All in excess thereof	6½c. per kw-hr.

Minimum charge, 75c. per month.
Minimum charge for power, $1 per hp.
Discount of 1c. per kw-hr. if bill is paid by the tenth of the month.

HOLTON. Population, 2842. Municipal Electric Light and Water Works. Maximum rate, 15c per kw-hr. Minimum monthly charge, 75c.

HOME. Population, 450. Served by Raber-Pierce Electric Company. Junction City. Lighting, 10c per kw-hr. $1 per month minimum. Power, 5c per kw-hr.

HOPE. Population, 575. Energy is furnished by the Herington plant. The lighting rates are practically the same as those of Herington. The power rate on a 5 h. p. motor or over is 7c per kw-hr. with a $2.50 minimum monthly charge.

HORTON. Population, 4500. Municipal Water and Light Plant.

STREET LIGHTING RATES:

120 series lamps, 6.6 amp., 60 watts, moonlight to midnight schedule, $960 total per year.

LIGHTING RATES:

1 to 10 kw-hrs	13c. per kw-hr.
Next 11 to 50 kw-hrs	11c. per kw-hr.
Next 51 to 100 kw-hrs	10c. per kw-hr.
Next 101 to 200 kw-hrs	9c. per kw-hr.
Next 201 kw-hrs. and over	8c. per kw-hr.

Minimum monthly bill, 75c. per month.

POWER RATES:

1 to 300 kw-hrs	5½c. per kw-hr.
301 to 624 kw-hrs	5c. per kw-hr.
625 kw-hrs. and over	4½c. per kw-hr.

Minimum monthly bill, $1.25 per month.
Ten per cent discount on all bills if paid before the 18th.

HUMBOLDT. Population, 2350. Humboldt Mill and Power Company.

STREET LIGHTING:

100 series C Mazda lamps, 5.5 amp., 80 watts, all-night schedule, $16 per year.

LIGHTING RATE:

1 to 49 kw-hrs	7c. per kw-hr.
50 to 99 kw-hrs	6c. per kw-hr.
100 to 199 kw-hrs	5c. per kw-hr.
200 to 299 kw-hrs	4c. per kw-hr.
300 to 399 kw-hrs	3½c. per kw-hr.
400 kw-hrs. and over	3c. per kw-hr.

POWER RATES:

Given as 2c. to 5c. per kw-hr., depending on amount consumed.

Minimum of all bills 75c. per month. A penalty of 10 per cent is added to bills if not paid by the tenth.

$5 deposit is made for each meter, which is refunded when meter is taken out.

HUTCHINSON. Population, 16500. United Water, Gas and Electric Company.

140 7.5 amp. arcs at	$64 per year.
200 clusters of 100-watt lamps, at	39 per year.
70 7.5 amp. Mazda lamps, at	17 per year.

Dusk to dawn service. Company renews lamps.

COMMERCIAL LIGHTING: 5c. to 3c. per kw-hr.

RESIDENCE LIGHTING: 5c. per kw-hr.

POWER RATE: 5c. to 1c. per kw-hr.

The company owns all meters and charges no rental. All rates as given are net.

INDEPENDENCE. Population, 10,480. Kansas Gas and Electric Company. Number of customers, 1190.

STREET LIGHTING:

43 arcs, 6.6 amp., 320-watt lamps, all-night schedule	$66.00 each per year.
22 Tungsten, 60 c. p. lamps, all-night schedule	15.00 each per year.
19 Tungsten, 80 c. p. lamps, all-night schedule	17.00 each per year.
47 Tungsten, 100 c. p. lamps, all-night schedule	20.00 each per year.
4 Tungsten, 250 c. p. lamps, all-night schedule	32.50 each per year.
28 Tungsten, 400 c. p. lamps, all-night schedule	45.00 each per year.

Renewals are furnished by the company.

RESIDENTIAL LIGHTING:

10c. per kw-hr. for consumption as shown by meter in customer's residence.

Minimum monthly charge, $1.

NOTE.—In case of any customer using a mercury arc rectifier, for charging of an electric automobile, and providing the current for both the residence and the garage can be metered with one meter, a net rate of 8c. per kw-hr. is made, with the understanding that customer will not operate his mercury arc rectifier during early evening hours, or in other words, during the peak-load period.

COMMERCIAL LIGHTING:

Meter rate:

8c. net per kw-hr. for any business closing at 7:00 p. m.
7c. net per kw-hr. for any business closing at 10:00 p. m.
6c. net per kw-hr. for any business closing at midnight.
5c. net per kw-hr. for any business open all night.

Minimum monthly charge, $1.

ADVERTISING LIGHTING:

Consisting of sign, outline, display window and spectacular lighting. Burning from dusk until midnight, every night, under power company control.

Per watt rated capacity of connected load per month, 1c. net.

Minimum monthly charge, $1.

INDUSTRIAL POWER. (Customer's option):

Meter rate:

For first 100 kw-hrs. per month	8c.	per kw-hr., net.
For next 100 kw-hrs. per month	6c.	per kw-hr., net.
For next 100 kw-hrs. per month	5c.	per kw-hr., net.
For next 200 kw-hrs. per month	4c.	per kw-hr., net.
For next 1,000 kw-hrs. per month	3½c.	per kw-hr., net.
For next 3,500 kw-hrs. per month	3c.	per kw-hr., net.
All over 5,000 kw-hrs. per month	2½c.	per kw-hr., net.

Minimum monthly charge, $1 per hp.

INDUSTRIAL POWER. (Customer's option):

Meter rate: (For continuous service):

$1.50 fixed charge per kilowatt connected load or maximum demand per month; plus an energy charge as follows:

For first 100 kw-hrs. per month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	3c. per kw-hr.
For next 3,500 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

For twenty-hour off-peak service.

$1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

The customer will be required to furnish a time switch for off-peak service.

IOLA. Population, 9035. Municipal Light and Water Plant.

STREET LIGHTING:

Paid by general lighting fund.

GENERAL METER RATES:

Minimum charge per month, $1.
Peak load per kw-hr., 4c.
Day load per kw-hr. guaranteed.

2 hours	3½c.
3 hours	3¼c.
4 hours	3c.
5 hours	2¾c.
6 hours	2½c.
7 hours	2¼c.
8 hours	2c.

The above rate for electric power for day service or non-peak load as follows: between the hours of 1 a. m. and 6 p. m. for a guranteed consumption of two hours per day for each kw. capacity of connected load, the rate shall be 3½c. per kw-hr.; and for each additional hour per day of guaranteed use per kw. capacity of connected load, a reduction of ¼c. shall be made until a minimum of 2c. shall be reached at a gurantee of 8 hours load per kw. of connected capacity as per above schedule.

FLAT RATES:

Minimum charge per month is $1.

2 c. p. sign lights			$0.05
4 c. p. service lights	$0.10	Sign lights	0.08
8 c. p. service lights	0.20	Sign lights	0.15
16 c. p. service lights	0.35	Sign lights	0.30
25 c. p. service lights			0.45
32 c. p. service lights			0.70
50 c. p. service lights			0.90
100 c. p. service lights			1.75
25-watt service lights			0.20
40-watt service lights			0.30
50-watt service lights			0.35
60-watt service lights			0.45
100-watt service lights			0.75

Lamps burning all day, 50 per cent additional.
Arc: No. 1, $5; No. 2, $3, October to April; No. 2, $2, April to October.
Motors: 1-10 hp., 90c; ½ hp., $2; 1 hp., $3.50.
Fans: 8-inch, 50c.; 10-inch, 50c.; 12-inch, 70c.; ceiling, $1.25.
Domestic rate: Iron, 1-8c. per month. Minimum, 50c.
Commercial rate- Iron, ½c. per month. Minimum, $1.

JAMESTOWN. Population, 462. Municipal Electric Light and Water Plant. Power furnished by the Concordia Electric Light Company. Circuits: a. c., day and night lighting, 110 v.; a. c., day and night motor, 220 v., 3 phases. Number of customers, 136.

STREET LIGHTING:

24 series Mazda lamps, 100 watts; 6 months, 4:30 to 12 p. m.; 6 months, 8:00 to 12 p. m. No charge.

COMMERCIAL LIGHTING:

Rate not given. Meters are owned and furnished by the city.

COMMERCIAL POWER:

Over 5 hp., 7.5c. per kw-hr., with graduated scale.

JUNCTION CITY. Population, 5598. Union Light and Power Company. Circuits: a. c., day and night lighting, 115 v.; a. c., day and night motor, 230 v.

STREET LIGHTING:

140 series lamps, 7.5 amp., 40 c. p., all-night schedule	$16.20 per year.
16 series lamps, 7.5 amp. arcs, all-night schedule	72.00 per year.

Renewals are furnished by the company.

COMMERCIAL LIGHTING:

Meter rate: Unit equivalent to 50 watts.

Under 2 kw-hrs., per unit	10c. per kw-hr.
2 kw-hrs. and under 5 kw-hrs., per unit	9c. per kw-hr.
5 kw-hrs. and under 10 kw-hrs., per unit	8c. per kw-hr.
10 kw-hrs. and under 15 kw-hrs., per unit	6c. per kw-hr.
15 kw-hrs. and over	5c. per kw-hr.

Flat rate, none.

COMMERCIAL POWER:

Power rates or table from which a rate is based.

NOTE.—A charge of 10 kw-hrs. per horsepower connected at 10c. per kw-hr. to equal minimum charge. No service furnished for less than $1 per month.

Schedule: Under 5 hp.:

10 kw-hrs. and less per month	10c. per kw-hr.
20 kw-hrs. and over 10 kw-hrs. per month	9c. per kw-hr.
40 kw-hrs. and over 20 kw-hrs. per month	8c. per kw-hr.
50 kw-hrs. and over 40 kw-hrs. per month	7c. per kw-hr.
60 kw-hrs. and over 50 kw-hrs. per month	6c. per kw-hr.
70 kw-hrs. and over 150 kw-hrs. per month	5c. per kw-hr.

Over 5 hp.:

50 kw-hrs. and under 100 kw-hrs. per month	6c. per kw-hr.
100 kw-hrs. and under 150 kw-hrs. per month	5c. per kw-hr.
150 kw-hrs. and under 500 kw-hrs. per month	4c. per kw-hr.
500 kw-hrs. and under 850 kw-hrs. per month	3.5c. per kw-hr.
850 kw-hrs. and under 1,500 kw-hrs. per month	3c. per kw-hr.
1,500 kw-hrs. and under 3,000 kw-hrs. per month	2.5c. per kw-hr.
3,000 kw-hrs. and under 6,000 kw-hrs. per month	2c. per kw-hr.
6,000 kw-hrs. and under 14,000 kw-hrs. per month	1.5c. per kw-hr.
14,000 kw-hrs. and under 28,000 kw-hrs. per month	1¼c. per kw-hr.

KACKLEY. Population, 250. (See Burr Oak).

KANSAS CITY. Population, 82,331.

STANDARD ELECTRIC LIGHT COMPANY. (Absorbed Consolidated Electric Light and Power Company.) Affiliated with the Kansas City Electric Light Company, Kansas City, Mo., now the Kansas City Light and Power Company. Without franchise rights in Kansas City and withdrawing service as fast as it can be taken over by the municipal plant. Energy transmitted from Kansas City Light and Power Company of Kansas City, Mo.

COMMERCIAL LIGHTING:

Business only:

Burning hours per day.	*Kw-hrs. consumed per month per 50-watt lamp.*	*Rate per kw-hr.*	*Minimum guaranteed per lamp per month.*
0 to 2-3		10c.	None.
2-3	1.0	9c.	10c.
1	1.5	8c.	12c.
2	3.0	7c.	21c.
3	4.5	6c.	27c.
4	6.0	5c.	30c.
6	9.0	4.5c.	33.75c.
8	12.0	4c.	36c.
10	15.0	3.5c.	52c.
12	18.0	3 1-8c.	56c.

20 50-watt lamps, minimum based on full load; 20 to 50 50-watt lamps, minimum based on 90 per cent load; 50 to 150 50-watt lamps, minimum based on 80 per cent load; 150 to 300 50-watt lamps, minimum based on 70 per cent load; 300 to 600 50-watt lamps, minimum based on 60 per cent load; 600 and over 50-watt lamps, minimum based on 50 per cent load.

Rates for churches:

10c. per kw-hr.............................. Minimum, $1.00 per month.
8c. per kw-hr.............................. Minimum, 10.00 per month.
7c. per kw-hr.............................. Minimum, 20.00 per month.
6c. per kw-hr.............................. Minimum, 30.00 per month.

Lighting rates to electric sign maintenance companies:

Less than 2,500 kw-hrs. per month....... 5.25c. per kw-hr.; minimum, none.
3,500 to 11,000 kw-hrs. per month....... 4.75c. per kw-hr.; minimum, $175.
11,000 to 22,000 kw-hrs. per month...... 4.20c. per kw-hr.; minimum, 495.
22,000 to 37,000 kw-hrs. per month...... 4.00c. per kw-hr.; minimum, 880.
37,000 to 70,000 kw-hrs. per month...... 3.70c. per kw-hr.; minimum, 1,387.
More than 70,000 kw-hrs. per month..... 3.20c. per kw-hr.; minimum, 2,450.

Less a 5 per cent discount for prompt payment.

RESIDENTIAL LIGHTING:

Flat rate service:

For lighting in any residence or apartment for the first three units, viz., kw-hrs., per room, minimum 3 rooms per month, (only including as rooms such ordinarily considered by architect's rating), 11c. per unit, and for all units additional in the same month 5c. per unit. Minimum bill, 50c. per month. All bills subject to a cash discount of 10 per cent where payment therefor is made on or before the tenth day of the month following that in which the service is rendered.

Date effective March 1, 1914.

COMMERCIAL POWER:

Small power—intermittent service:

	Rate per kw-hr.				
	8c.	*7c.*	*6c.*	*5c.*	*4c.*
Connected hp.	*Minimum monthly payment.*				*(Factory rate.)*
1	$1.00	$1.40			
2	1.20	1.80			
3	1.40	2.20	$2.70		
4	1.60	2.60	3.30	$3.70	
5	1.80	3.00	3.90	4.50	$5.00
6	2.00	3.40	4.50	5.30	6.00
7	2.20	3.80	5.10	6.10	7.00
8	2.40	4.20	5.70	6.90	8.00
9	2.60	4.60	6.30	7.70	9.00
10	2.80	5.00	6.90	8.50	10.00
11	3.00	5.40	7.50	9.30	
12	3.20	5.80	8.10	10.10	
13	3.40	6.20	8.70	10.90	
14	3.60	6.60	9.30	11.70	
15	3.80	7.00	9.90	12.50	
16	4.00	7.40	10.50	13.30	
17	4.20	7.80	11.10	14.10	
18	4.40	8.20	11.70	14.90	
19	4.60	8.60	12.30	15.70	
20	4.80	9.00	12.90	16.50	

Factory power: continuous service:

Rate is 4c. per kw-hr. with 5 per cent discount on first $100 and 10 per cent discount on excess over $100, for prompt payment. Monthly minimum, $1 per hp. connected, subject to above discount up to and including 10 hp. Minimum monthly guarantee never more than $10.

Date effective, April 15, 1913.

Passenger and freight elevator service:

Hp.	Minimum.	Rate.	Hp.	Minimum.	Rate.
1	$1.00	8c.	26	$7.25	6c.
2	1.25	8c.	27	7.50	6c.
3	1.50	8c.	28	7.75	6c.
4	1.75	8c.	29	8.00	6c.
5	2.00	8c.	30	8.25	6c.
6	2.25	8c.	31	8.50	6c.
7	2.50	8c.	32	8.75	6c.
8	2.75	8c.	33	9.00	6c.
9	3.00	7c.	34	9.25	6c.
10	3.25	7c.	35	9.50	6c.
11	3.50	7c.	36	9.75	6c.
12	3.75	7c.	37	10.00	5c.
13	4.00	7c.	38	10.25	5c.
14	4.25	7c.	39	10.50	5c.
15	4.50	7c.	40	10.75	5c.
16	4.75	7c.	41	11.00	5c.
17	5.00	7c.	42	11.25	5c.
18	5.25	7c.	43	11.50	5c.
19	5.50	7c.	44	11.75	5c.
20	5.57	7c.	45	12.00	5c.
21	6.00	7c.	46	12.25	5c.
22	6.25	7c.	47	12..50	5c.
23	6.50	7c.	48	12.75	5c.
24	6.75	7c.	49	13.00	5c.
25	7.00	6c.			

Date effective, April 15, 1913.

Low voltage maximum demand service:

$4.50 per kilowatt of maximum demand, plus 1c. per kw-hr., less 5 per cent discount on first $100 and 10 per cent discount on excess over $100 per month for prompt payment.

This contract is applicable to customers using both light and power, but it is not intended as a lighting contract. The company does not offer this contract to customers where the consumption for power is not at least double the consumption for light. The company does not guarantee voltage regulation under this contract as it would under a lighting contract.

The maximum demand is determined as the rate of power consumption shown by the average of the highest in the a. m. and the two highest in the p. m. half-hour readings as shown on our watt-hour meter.

Rate effective, April 15, 1913.

Off-peak low voltage maximum demand service:

$2.50 per kilowatt of maximum demand plus 1c. per kw-hr., less 5 per cent discount on first $100 per month and 10 per cent discount on excess over $100 per month for prompt payment. Customers agree not to use current between the hours of 4 p. m. and 7 p. m., from November 1 to March 1.

Off-peak voltage demand is determined as the rate of power consumption shown by the highest half-hourly .eading on a watt-hour meter.

High voltage maximum demand service:

$2 per kilowatt of maximum demand plus 1c. per kw-hr., less 5 per cent discount for prompt payment. This contract is not generally writeen on less than 100 kilowatts of demand, as under it the customer must purchase and maintain all high-voltage apparatus, either in motors or transformers, enabling him to use the current. In general, customers do not care to make this investment and maintain the service that is required of them unless they have a demand of 100 kilowatts. High-voltage demand in excess of 300 kilowatts, $1.33 1-3 per kilowatt of maximum demand, plus ¾c. per kw-hr., less 5 per cent discount for prompt payment.

Fan service:

Limited to summer use, approximately three months, 18c. net, per kilowatt hour, with a $3 minimum. 50c. for each additional fan connected.

Rectifier service.

5c. per kw-hr., with a minimum charge of $3 per month, less a 5 per cent discount for prompt payment. Customer agrees not to use service between the hours of 4 p. m. and 10 p. m.

Floor surfacing service:

8c. per kw-hr., with a minimum charge of $5 per month. 5 per cent discount for prompt payment. Customer agrees to pay company cost of connecting and disconnecting service, with a minimum charge of $2.

Electric welder service:

50c. per month per kilowatt of transformer connected, plus 10c. per kw-hr., with a 5 per cent discount for prompt payment.

Date effective, April 15, 1913.

Temporary service for construction purposes:

4c. per kw-hr., with a minimum monthly charge of $1 per hp., connected load, but never less than $5, with a discount of 5 per cent for prompt payment. Customer agrees to reimburse company for cost of connecting and disconnecting service.

STREET LIGHTING:

City arc lighting:

6.6 amp., d. c., 4-amp., magnetite lamps, and 500-watt incandescent lamps; all-night schedule, every night, $55 per lamp per year.

Series incandescent lighting:

250-watt lamps, all-night schedule, every night, $34 per lamp per year.

Parellel lighting:

4 100-watt lamps in a cluster, burning from dusk to 1 a. m., every night, $32 per cluster.

Boulevard and park incandescent lighting: (Underground distribution; parallel):

1 100-watt lamp per standard, all-night schedule, every night, $21 per lamp per year.

Date effective, December 31, 1913.
Rules and regulations pertaining to lamps.
Free renewals: Of all carbon and gem lamps to all customers who pay in excess of 5c. per kw-hr.
Mazda lamp renewals: On the following basis where customer makes original deposit as shown. This schedule is in effect December 1, 1913.

Size of lamp.	*Original purchase price, clear.*	*Original purchase price, frosted.*	*Renewal basis, Clear.*	*Renewal basis, frosted.*
100-watt,	50c.	57c.	Free.	Free.
60-watt,	25c.	28c.	Free.	Free.
40-watt,	25c.	28c.	10c.	12c.
25-watt.	25c.	28c.	12c.	14c.
20-watt,	25c.	28c.	14c.	16c.
15-watt,	25c.	28c.	18c.	21c.
10-watt,	25c.	28c.	21c.	23c.

Incandescent lamp renewals:
To secure renewal privilege on incandescent lamps the customer deposits 25c. for each carbon filament or gem lamp, deposit being refunded to him upon discontinuation of service.
Arc lamp rental: 25c per month.
Date effective, April 13, 1913.

MUNICIPAL ELECTRIC LIGHT PLANT. Circuits: a. c. day and night lighting circuit, 110 v.; a. c. day and night motor circuit, 2300–6600 v., 3 hp. Number of customers, about 7000.

STREET LIGHTING:

416 arcs, 500-watts....................................$55 per year.
401 incandescents, 100-watts.................................. 12 per year.

LIGHTING RATES:

Hours burning per day, average.	*Kw-hrs. consumed per kilowatt connected.*	*Rate per kw-hr.*	*Minimum per kilowatt connected.*
½	15	6c.	$0.80
¾	17	5¾c.	0.90
1	20	2½c.	1.00
1¼	25	5¼c.	1.10
1½	30	5c.	1.20
2	40	4¾c.	1.50
2½	50	4½c.	1.75
3	65	4¼	2.00
3½	80	4c.	2.25
4	95	3¾c.	2.75
4½	120	3½c.	3.00
5	150	3¼	3.25
6	200	3c.	3.50

All residences 75c. minimum and 6c. rate.

POWER RATES:

Hours burning per day, average.	*Kw-hrs. consumed per killowatt connected.*	*Rate per kw-hr.*	*Minimum per kilowatt connected.*
1	10	3c.	$0.80
2	15	2¾c.	0.85
3	22	2½c.	0.93
4	35	2¼c.	1.17
6	50	2c.	1.66
8	70	1¾c.	1.82
10	95	1½c.	1.95
12	150	1¼c.	2.05
15	300	1	2.25

Unity power factor motors are granted 1-8c. lower rate than is figured by this rule. Heating and cooking rate 3c. per kw-hr., and 80c. per kw. connected.

KINSLEY. Population, 1547. Kinsley Electric Light and Power Company. Maximum rate, 15c per kw-hr. with 10 per cent discount for prompt payment.

KINGMAN. Population, 2570. Municipal Light and Power Company. Circuits: day and night lighting, 215 v. s. p., 60 cycles. day and night motor, 115 to 220 v., 1 and 3 phase. Number of customers, 520.

STREET LIGHTING:

35 multiple lamps, 110 v., 100-watts, all-night schdule; 70 multiple lamps, 110 v., 60-watts, to midnight schedule; 91 series lamps, 5.5 amp., 100-watt, moonlight schedule; 17 series lamps, 5.5 amp., 60-watt, moonlight schedule; total, $150 month from general fund of city.

COMMERCIAL LIGHTING:

First 100 kw-hrs...10c. per kw-hr.
Next 50 kw-hrs... 9c. per kw-hr.
Next 50 kw-hrs... 8c. per kw-hr.
All above 200 kw-hrs.................................. 7c. per kw-hr.

Minimum charge of $1 per month.

COMMERCIAL POWER:

Day run only:

First 100 kw-hrs	6c. per kw-hr.
Next 100 kw-hrs	5½c. per kw-hr.
Next 100 kw-hrs	5c. per kw-hr.
All above 300 kw-hrs	4c. per kw-hr.

Power used only between sunset and midnight, 6c. per kw-hr., with minimum charge of $2 per month.

Special rates: For cooking, with a deposit of the cost of meter, 3c. per kw-hr.; for power, with a deposit of the cost of meter, day use only, 3c. per kw-hr., with $2 minimum monthly charge.

A penalty of 20 per cent is added to all bills not paid before the tenth of the month.

All meters are owned by the city.

KIOWA. Population, 1520. Municipal Electric Light and Water Works. Maximum rate, 15c per kw-hr.

LARNED. Population, 2911. C. W. Smith Electric and Ice Company. Circuits: Day and night lighting, 104 v., 60 cycles. Day and night motor, 104 to 208 v., 60 cycles 1 phase. Number of customers, 620.

STREET LIGHTING:

213 Mazda lamps, 60-watt; 1 hour after sundown until 11 p. m.; Saturday until 12 p. m.; 75c. each per month. 17 Mazda lamps, 60-watt; all-night schedule, $1.15 each per month. Renewal furnished by the company.

COMMERCIAL LIGHTING:

Meter rates. Residence rates:

First 40 kw-hrs	12.5c. per kw-hr.
Next 60 kw-hrs	10c. per kw-hr.

All over 100 kw-hrs. get benefit of business rate.

Business rate:

First 40 kw-hrs	10c. per kw-hr.
Next 60 kw-hrs	9c. per kw-hr.
Next 100 kw-hrs	8c. per kw-hr.
All over 200 kw-hrs	7c. per kw-hr.

The above rates are subject to a discount of 20 per cent if paid in ten days on a bill of $2 or more.

COMMERCIAL POWER: Special: mostly 5c. per kw-hr.

COOKING RATE: 5c. per kw-hr., with no discount.

Minimum rates: $1 per month and 25c. per month for meter rent when company owns meter.

LAWRENCE. Population, 12,374. Kansas Electric Utilities Company. Buys energy from the Bowersock Mills and Power Company. Circuits: Day and night lighting, 112 to 115 v., and 108 to 112 v., 60 cycles. Day and night motor, 110 to 220 v., 1 and 3 phase, 60 cycles. Number of customers, 1900.

STREET LIGHTING:

20 6.6 amp., 425-watt lamps, all-night schedule	$72 each per year.
123 6.6 amp., 425-watt lamps, midnight schedule	48 each per year.
100 6.6 amp., 100-watt lamps, midnight schedule	24 each per year.

Renewals are furnished by company.

COMMERCIAL ENERGY RATES:

Meter rate:

8 to 30 kw-hrs	10c. per kw-hr., with a discount of 5 per cent.
30 to 100 kw-hrs	9c. per kw-hr., with a discount of 6 per cent.
100 to 300 kw-hrs	8c. per kw-hr., with a discount of 7 per cent.
300 to 600 kw-hrs	7c. per kw-hr., with a discount of 8 per cent.
600 to 1,000 kw-hrs	6c. per kw-hr., with a discount of 9 per cent.
1,000 and over of kw-hrs	5c. per kw-hr., with a discount of 10 per cent.

Discount given only when bill is paid before tenth of the month.

LEAVENWORTH. Population, 19,363. Leavenworth Light, Heat and Power Company. Controlled by United Gas and Electric Company, New York.

STREET LIGHTING:

130 arc lamps, 450-watt	$70 each per year.
193 Mazda lamps, 40-watt, all-night schedule	14 each per year.

ELECTRICAL ENERGY RATES:

A—RESIDENCE LIGHTING:

Rate, 11c. per kw-hr. Discount, 1c. per kw-hr. if paid in ten days from date of bill at office of company. Guarantee, $1 per month, per meter.

B—COMMERCIAL LIGHTING:

Rate, 11c. per kw-hr. for a monthly consumption equal to the first thirty hours use of the lamps; 6c. per kw-hr. for all in excess. Prompt payment discount, 1c. per kw-hr. if paid on or before the tenth of the month.

Additional quantity discount:

For average use of 60 hours each month of lamps connected	5 per cent.
For average use of 75 hours each month of lamps connected	7 per cent.
For average use of 90 hours each month of lamps connected	10 per cent.
For average use of 120 hours each month of lamps connected	10.5 per cent.
For average use of 150 hours each month of lamps connected	15 per cent.
For average use of 210 hours each month of lamps connected	17 per cent.
For average use of 300 hours each month of lamps connected	20 per cent.
For average use of 360 hours each month of lamps connected	25 per cent.
For average use of 380 hours or over	33 1-3 per cent.

Guarantee, $1 per month per meter.

C—OPTIONAL LIGHTING RATE:

Rate, 11c. per kw-hr. for a monthly consumption equal to the first 30 hours use of the lamps connected; 5c. per kw-hr. for all in excess.

Prompt payment discount: 1c. per kw-hr. will be allowed if bills are paid on or before the tenth of the month.

Additional contract discount:

For a total of 10 kw. of lamps connected and up to 15 kw	5 per cent.
For a total of 15 kw. of lamps connected and up to 20 kw	10 per cent.
For a total of 20 kw. of lamps connected and up to 50 kw	15 per cent.
For a total of 50 kw. and over	20 per cent.

Guarantee $1 per month per meter.

D—COMMERCIAL POWER:

Primary charge:

Horsepower connected, ½; monthly charge	$2.00
Horsepower connected, 1; monthly charge	2.50
Horsepower connected, 2; monthly charge	3.75
Horsepower connected, 3; monthly charge	5.00
Horsepower connected, 4; monthly charge	6.25
Horsepower connected, 5; monthly charge	7.50
Horsepower connected, 6; monthly charge	8.75
Horsepower connected, 7; monthly charge	10.00
Horsepower connected, 8; monthly charge	11.00
Horsepower connected, 9; monthly charge	12.00
Horsepower connected, 10; monthly charge	13.00
Horsepower connected, 15; monthly charge	18.00
Horsepower connected, 20; monthly charge	23.00
Horsepower connected, 25; monthly charge	27.50
Horsepower connected, 30; monthly charge	31.00
Horsepower connected, 40; monthly charge	37.00
Horsepower connected, 50; monthly charge	44.00

For hp. of connected load other than shown above, the primary charge shall be at a rate per hp. equivalent to the rate of the nearest hp. as shown above.

Energy charge: 2¾c. per kw-hr.

Determination of demand: The hp. connected will be considered as equivalent to the rated hp. of motor or motors installed.

Prompt payment discount: 1c. per kw-hr. will be allowed if bills are paid on or before the tenth of the month.

Additional contract discount: When the connected load exceeds 100 hp., but less than 150 hp., the consumer will be entitled to a discount of 10 per cent applicable only to the above primary charge; if the connected load is in excess of 150 hp., a discount of 15 per cent will be applied to the primary charge.

Guarantee: The consumer guarantees a monthly bill equivalent to the primary charge corresponding to the hp. installed.

E—WHOLESALE POWER:

Demand charge:

First 25 kw. of demand each month at	$2.50
Next 25 kw. of demand each month at	2.00
Next 50 kw. of demand each month at	1.50
All over 100 kw. of demand each month at	1.00

Energy charge: 1½c. per kw-hr. for all current used.

Determination of demand: The demand to be considered and paid for hereunder shall be the highest minute demand previously recorded by a demand meter or other suitable indicating instrument, but in no event less than the guaranteed demand of 25 kw. The company may at its option and in lieu of a demand meter, assume 75 per cent of the connected load if in one motor and in 65 per cent if in more than one motor.

Power factor: The consumer shall at all times take and use power in such manner that the power factor shall be as near 100 per cent as possible, but when the power factor is less than 80 per cent then the demand to be charged and paid for shall be obtained by multiplying the demand shown by the meter at the time of measurement by 80 and multiplying the product thus obtained by the actual power factor.

Discount for prompt payment. A discount of ½c. per kw-hr. will be allowed if all bills are paid on or before the fifteen of the month.

Guarantee: The monthly guarantee shall be equivalent to a minimum monthly demand of not less than 40 per cent of the total connected load and in no event less than the guaranteed 25

kw. at the demand charges above. The above guarantee is net; 10 per cent will be added if not paid on or before the fifteenth of the month following the month for which the bill is rendered.

Standard riders applicable to this contract:

Rider No. 1.—Off-peak service: When executed by the consumer and accepted by the company the modification shall be such that the excess of "off-peak" demand shall be charged at half the wholesale demand charges normally applying to such excess, it being agreed that "on peak" hours shall be from 4:30 p. m. to 9:00 p. m., during the months of November to January, inclusive, and from 6:00 p. m. to 9:00 p. m., during the months of February to October, inclusive.

The kw-hr. charge, minimum bill and all other terms and conditions are to remain as specified above.

Rider No. 2—Lighting service: Applying to wholesale power rate with incidental lighting. When executed by the consumer and accepted by the company the modification shall be such that lighting may be supplied under this contract when demand for same does not exceed 10 per cent of the power demand, it being agreed that the power demand shall be increased by 100 per cent of the rated capacity of the installed lighting apparatus.

Battery charging rate, 6c. per kw-hr., with a $5 minimum monthly charge.

LEBANON. Population, 731. Municipal Light, Water and Power Plant. Circuits: Day and night a. c., lighting, 110 v. Day and night motor, 2200-220 v., 1 and 3 phases. Number of customers, 163.

STREET LIGHTING:

37 series lamps, 6.6 amp., all-night schedule; 48 white-way lamps, 2,240 watts, total, 3 burn until midnight, 1 on until morning. Flat rate sum of $75 per month. Plant furnishes renewals.

COMMERCIAL LIGHTING:

Meter rate:

1 to 25 kw-hrs. at	12c. per kw-hr.
25 to 30 kw-hrs. at	$3.00.
30 to 50 kw-hrs. at	10c. per kw-hr.
50 to 55 kw-hrs. at	$5.00.
55 to 105 kw-hrs. at	9c. per kw-hr.
105 to 171 kw-hrs. at	8c. per kw-hr.
171 and over of kw-hrs. at	7c. per kw-hr.

Minimum rate, $1 per month.

COMMERCIAL POWER:

Meter rate:

6c. per kw-hr. with minimum of $1 for 1 hp. and 50c. for each additional hp.

HEATING RATE:

4c. per kw-hr., with no minimum charge.

Meters are owned by consumers or furnished by company at 25c. per month rental.

LIBERAL. Population, 1716. Liberal Light, Ice and Power Company. Circuits: Day and night lighting, 110 v. Day and night motor, a. c., 220 v. Number of customers, 300.

STREET LIGHTING:

60 series Mazda 80-watt lamps, all-night schedule, every night, $26.40 each per year. Company furnished renewals.

COMMERCIAL LIGHTING:

First 25 kw-hrs. per month	15c. per kw-hr.
Next 50 kw-hrs. per month	10c. per kw-hr.
Next 125 kw-hrs. per month	8c. per kw-hr.
All over 200 kw-hrs. per month	6c. per kw-hr.

COMMERCIAL POWER:

10c. per kw-hr. for first 100 kw-hrs. per month; 6c. per kw-hr. for balance.

Special rates: Off-peak cooking rate of 5c. per kw-hr.

Minimum rate: $1.25 per month.

A meter deposit of $12.50 is made on which 6 per cent interest is paid to the consumer.

A 10 per cent discount is given on all bills for prompt payment.

LINDSBORG. Population, 1939. Municipal Water and Light Plant. Circuits: Day and night lighting, 110 to 220 v. Motor circuit, a. c., 110 to 220 v. 1 and 3 phases. Number of customers, 310.

STREET LIGHTING:

38 Tungsten and A. B. arc lamps, 7.6 amp., 250 and 200-watt; total per year, $2,100.

COMMERCIAL LIGHTING:

For the first 30 kw-hrs	12.5c. per kw-hr.
From 30 to 50 kw-hrs	10c. per kw-hr.
From 1 to 150 kw-hrs., if party uses 50 kw-hrs. per month	10c. per kw-hr.
All over 150 kw-hrs	8c. per kw-hr.

COMMERCIAL POWER:

For the first 100 kw-hrs	7c. per kw-hr.
All over 100 kw-hrs	6c. per kw-hr.

Minimum rate, $1 per month.
Meters are owned by the consumers.

LINN. Population, 500. (See Aurora).

LYNDON. Population, 763. Municipal Electric Light Plant. Sells power in bulk to Osage County Light and Power Company. Circuits: Night lighting, a. c., 110 v., 220 v. motor, 1 phase. Number of customers, 270.

STREET LIGHTING:

110 Mazda lamps, 32 100-watt lamps, total, $615 per year.

COMMERCIAL LIGHTING:

Meter rate:

1 to 25 kw-hrs	10c. per kw-hr.
25 to 50 kw-hrs	9c. per kw-hr.
50 to 100 kw-hrs	8c. per kw-hr.
100 to 200 kw-hrs	7c. per kw-hr.
200 to 400 kw-hrs	6c. per kw-hr.
400 to 700 kw-hrs	5c. per kw-hr.
700 to 1,000 kw-hrs	4c. per kw-hr.
1,000 and over of kw-hrs	3.5c. per kw-hr.

Minimum rate, 25c. per month.

COMMERCIAL POWER:

Current is furnished to an elevator company who supply all their own appliances, meters, etc., and use current only during the day, at 4c. per kw-hr. flat.

SPECIAL RATES:

Current is fed to the transmission lines of the Osage County Light and Power Company which feeds the towns of Melvern and Quenemo. The minimum for this line for the year was $1,487.50 and they consumed 54,720 kw-hrs. during the year.

The city consumes for pumping, lighting, etc., about 78,000 kw-hrs. per year, which is covered by a tax of .001.

Meters are rented at 25c. per month.

McCUNE. Population, 800. Municipal Electric Light Plant. Circuits: a. c., night lighting, 110 v. a. c., night motor, 110 to 220 v., 1 and 3 phases. Number of customers, 140.

STREET LIGHTING

13 250-watt and 47 100-watt lamps; total, $1200 per year.

COMMERCIAL LIGHTING:

8c. per kw-hr.; all service metered.
Minimum rate, 75c. per month.

McPHERSON. Population, 3546. Municipal Electric Light and Water Works. Circuits: Day and night lighting, a. c., 110 v. Day and night motor, 220 v. a. c.

STREET LIGHTING:

230 incandescent 6.6 and 5.5-amp. lamps, moonlight and all-night schedule: rate 3c. per kw-hr.

COMMERCIAL AND RESIDENCE LIGHTING:

Meter:

1 to 50 kw-hrs	10c. per kw-hr.
51 to 100 kw-hrs	8c. per kw-hr.
101 to 200 kw-hrs	7c. per kw-hr.
201 to 300 kw-hrs	6c. per kw-hr.
301 and above of kw-hrs	5c. per kw-hr.

Minimum of 75c. per month.

COOKING AND HEATING:

1 to 50 kw-hrs	4c. per kw-hr.
51 and above of kw-hrs	3c. per kw-hr.

Minimum of $1 per month.

POWER RATES:

Four cents (4c.) per kw-hr. with a minimum charge of $1 per month for the first 3 hp. connected, and 25c. for each additional connected hp. Provided that motor service for less than 1 hp. shall be installed on the regular lighting service and be treated and charged for the same as commercial and residence lighting.

For any quantity of current to be used for power where the consumer will agree to use not less than $50 worth per month or pay a minimum charge of $50 per month, for at least 12 months continuous service, the rate may be fixed at less than 4c. per kw-hr. upon recommendation of the superintendent and when approved by the board of commissioners.

COMMERCIAL SIGN RATES:

6c. per kw-hr. with a minimum charge of 75c. per month.

TRANSIENT RATES:

Consumers using electricity for fifteen days or less shall be charged 15c. per kw-hr. for any quantity used and no connections shall be made for less than $2.

A deposit of not less than $1.25 is required from each consumer to guarantee payment of bills and is refunded when service is discontinued. A written guarantee may be given in place of the deposit.

These rates were made effective January 18, 1916.

MANHATTAN. Population, 5722. Manhattan Ice, Light and Power Company. Circuits: Day and night lighting, a. c., 110 v., 60 cycles. Day and night motor, a. c., 2300 to 220 v., 3 phases.

STREET LIGHTING:

7 arcs 6.6 amp., 450 watts, all-night schedule, $70 per year each; 236 incandescent lamps, 6.6 amp., 100 c. p., all-night schedule $16 per year each; 41 white-way posts, 4 60-watt lamps, until 11 p. m., 1 100-watt lamps all night, $30 each per year.

Renewals are furnished by the company for an extra charge of $10 per year for arcs, $4 per year for series incandescent lamps and $6 per year per white-way post.

COMMERCIAL LIGHTING:

10c. per kw-hr. for the first 30 hours use of the active connected load per month; 6c. per kw-hr. for all excess over 30 hours use.

Minimum rate of 75c. per month.

COMMERCIAL POWER:

6c. per kw-hr. with discounts as follows:

149 kw-hrs	10 per cent.
150 to 249 kw-hrs	15 per cent.
250 to 349 kw-hrs	20 per cent.
350 to 449 kw-hrs	25 per cent.
450 to 549 kw-hrs	30 per cent.
550 to 649 kw-hrs	35 per cent.
650 to 749 kw-hrs	40 per cent.
750 to 849 kw-hrs	45 per cent.
850 to 999 kw-hrs	50 per cent.
1,000 to 1,249 kw-hrs	55 per cent.
1,250 and over	60 per cent.

For primary motors of 20 hp. or more only.

Minimum of $1 per hp. connected per month.

Discount of 10 per cent if paid by the tenth of the month.

Special rates: For primary motors on off-peak service under long-time contract, 2c. per kw-hr.

Manhattan Milling Company for excess water power above 400 kw., 1 1-10c. per kw-hr., or 7c. per barrel of product manufactured.

MANKATO. Population, 1155. Furnished by Concordia Electric Light Company.

STREET LIGHTING:

80 c. p. lamps, dusk to midnight moonlight schedule, $1 per month.

Sign lighting, 5c. per kw-hr.

COMMERCIAL LIGHTING:

First 20 kw-hrs	12c. per kw-hr.
Next 20 kw-hrs	11c. per kw-hr.
Next 20 kw-hrs	10c. per kw-hr.
Next 20 kw-hrs	9c. per kw-hr.
All over 80 kw-hrs	8c. per kw-hr.

Minimum, $1.50 monthly. No discount.

RESIDENCE LIGHTING:

15c. per kw-hr. Minimum, $1.35 per month.

Discount of 10 per cent for payment within five days.

RURAL SERVICE:

12c. per kw-hr. Minimum charge, $2 per month.

MARION. Population, 1841. Municipal Power Plant. Circuits: Day and night lighting, a. c., 110 v., 60 cycles. Day and night motor, a. c., 110 to 220 v., 1 and 3 phases. Number of customers, 272.

STREET LIGHTING:

About 150 series Tungsten 6.6 amp. 60-watt lamps, all-night schedule. No charge.

COMMERCIAL LIGHTING:

12c. per kw-hr. gross.
Discount of 10 per cent if paid before the tenth of the month.
Minimum rate of $1 per month.
Residence meters read every three months.
Plant also furnished power for municipal water works and septic tank.

MARQUETTE. Population, 715. Municipal Electric Light Plant. Maximum rate, 12.5c per kw-hr. Minimum monthly charge, 50c.

MARYSVILLE. Population, 2260. Marysville Light, Power and Water Company. Circuits: Day and night lighting and motor, 110 v. 1 and 3 phases.

STREET LIGHTING:

147 60-watt Mazda lamps, all-night schedule, $1.50 each per month; 48 100-watt Mazda lamps, all-night schedule.
Renewals are furnished by the company.

COMMERCIAL LIGHTING:

12c. per kw-hr. Motors of ¼ hp. and under will be connected on lighting meters and current charged for at lighting rates.
There will be a minimum charge of $1 per month per meter to cover readiness to serve expense.

COMMERCIAL POWER:

Meter rates:

First 50 kw-hrs. used per month	7c. per kw-hr.
Next 50 kw-hrs. used per month	6c. per kw-hr.
Next 400 kw-hrs. used per month	5c. per kw-hr.
Next 500 kw-hrs. used per month	4c. per kw-hr.
Over 1,000 kw-hrs. used per month	Special rates.

All consumers having a connected load of 2 hp. or under and over ¼ hp., will be charged a minimum of $1 per month to cover readiness to serve expense. Consumers having a connected motor in excess of 2 hp. will be charged a minimum of 50c. per hp. per month.

MEADE. Population, 664. Meade Light and Power Company. Maximum rate, 18c per kw-hr. Minimum monthly charge, $1.

MINNEAPOLIS. Population, 1895. Jackman Roller Mills. Circuits: a. c. day and night lighting and motor, 110 v., 60 cycles. Number of customers, 300.

STREET LIGHTING:

116 series 6.6 amp., 60-watt lamps, midnight moonlight schedule, $1.25 per lamp per month. Company furnishes renewals.

COMMERCIAL LIGHTING:

Meter rate:

First 30 kw-hrs	12.5c. per kw-hr.
Next 70 kw-hrs	10c. per kw-hr.
All over 100 kw-hrs	8c. per kw-hr.

Minimum rate: Residence, $1; commercial buildings, $1.50 per month.
Flat rates: 1 60-c. p. lamp or less, $1 per month; all over, 50c. per month.
No flat rates are given except where only 1 or 2 lamps are used.
Cooking rate: 5c. per kw-hr. for ranges.
Meters are all owned by the company.

MOUNDRIDGE. Population, 626. Municipal Electric Light and Water Works. Maximum rate, 15c per kw-hr. Minimum monthly charge, 50c.

MULBERRY. Population, 1500. Municipal Light and Water Department. Also supplies Burgess, Missouri. Number of customers, 292.

STREET LIGHTING—

80 incandescent 6.6 amp., 80 to 250-watt lamps, all-night schedule. No charge.

COMMERCIAL LIGHTING:

Meter rate, 11c. per kw-hr.
Flat rate, none except churches, at $1.
Commercial power: 2½, 3 and 4c. per kw-hr.
A discount of 10 per cent is given on bills for prompt payment.
All meters are owned by the company.

MULVANE. Population, 1084. Mulvane Ice and Cold Storage Company. Maximum rate, 15c per kw-hr., with 10 per cent discount for prompt payment.

NEODESHA. Population, 4000. Municipal Light Plant. Circuits: Day and night lighting, a. c., 110 v. Day and night motor, a. c., 220 v., 3 phases.

STREET LIGHTING:

52 arcs, 6.6 amp., 510 watts, moonlight schedule	Free.
7 type C Mazda, 500-watt lamps, monlight schedule	Free.

Renewals are furnished by the city.

COMMERCIAL LIGHTING:

Meter rate, 6c. per kw-hr.
Minimum rate, 50c per month.

COMMERCIAL POWER:

First 300 kw-hrs	3c. per kw-hr.
Next 200 kw-hrs	2.5c. per kw-hr.
All over 500 kw-hrs	2c. per kw-hr.

Consumers own their meters.

NESS CITY. Population, 712. Municipal Light and Power Company.

STREET LIGHTING:

16 Mazda 100-watt lamps, all-night moonlight schedule; 63 Mazda, 6.6 amp. lamps, all-night moonlight schedule; total, $900 per year.

COMMERCIAL LIGHTING:

Meter rate: 12.5c. per kw-hr., with a minimum of $1 per month.

COMMERCIAL POWER:

From 6 to 3.5c. per kw-hr., on a sliding scale, with a minimum of $3.50 per month.
A penalty of 10 per cent is added to accounts not paid by the tenth of the current month.
Meters are owned by the city and no rent is charged.

NEWTON. Population, 7862. Kansas Gas and Electric Company. Circuits: Day and night, a. c., lighting, 110 v., 60 cycles. Day and night motor, 2300 to 220 to 110 v., 3 phases, 60 cycles. Number of customers, 1900.

STREET LIGHTING:

8 6.4 amp., 100-watt lamps	$21 each per year.
129 6.4 amp., 80-watt lamps	19 each per year.
29 6.4 amp., 60-watt lamps	18 each per year.
15 6.4 amp. arcs	70 each per year.

Renewals are furnished by the city.

RESIDENTIAL AND COMMERCIAL LIGHTING:

Meter rates:

1 to 12 kw-hrs. per month	12c. per kw-hr.
13 to 40 kw-hrs. per month	10c. per kw-hr.
41 to 100 kw-hrs. per month	8c. per kw-hr.
All over 100 kw-hrs. per month	7c. per kw-hr.

Minimum monthly charge, 75c.

ADVERTISING LIGHTING. (Customer's option.)

Consisting of sign, outline, display window and spectacular lighting. Burning from dusk until midnight, every night, under power company control.
Per watt rated capacity of connected load per month, 1c. net.
Minimum monthly charge, $1.

INDUSTRIAL POWER. (Customer's option.)

Meter rate:

For first 100 kw-hrs. per month	8c. per kw-hr., net.
For next 100 kw-hrs. per month	6c. per kw-hr., net.
For next 100 kw-hrs. per month	5c. per kw-hr., net.
For next 200 kw-hrs. per month	4c. per kw-hr., net.
For next 1,000 kw-hrs. per month	3½c. per kw-hr., net.
For next 3,500 kw-hrs. per month	3c. per kw-hr., net.
All over 5,000 kw-hrs. per month	2½c. per kw-hr., net.

Minimum monthly charge, $1 per hp.

INDUSTRIAL POWER. (Customer's option.)

Meter rate (for continuous service):

For first 100 kw-hrs. per month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	3c. per kw-hr.
For next 3,500 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.
For twenty-hour off-peak service:
$1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above.
Less a discount of 10 per cent if paid within fifteen days from date of billing.
The customer will be required to furnish a time switch for off-peak service.

RURAL DOMESTIC LIGHTING AND POWER:

Meter rate: To apply in the territory adjacent to and outside of the corporate limits of Newton:

For first 30 kw-hrs. per month	13c. per kw-hr.
For next 60 kw-hrs. per month	11c. per kw-hr.
For next 120 kw-hrs. per month	10c. per kw-hr.
All over 210 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.
Minimum monthly charge for lighting service, $1.
Minimum monthly charge for power service, $1.

NORTON. Population, 1787. Municipal Light and Power Plant.

LIGHT AND POWER RATES:

First 30 kw-hrs	15c. per kw-hr.
Next 30 kw-hrs	12c. per kw-hr.
Next 50 kw-hrs	10c. per kw-hr.
Next 50 kw-hrs	9c. per kw-hr.
In excess of above	8c. per kw-hr.

Minimum monthly charges:

5-amp. meter	$1.00
10-amp. meter	1.50
15-amp. meter	2.00
20-amp. meter and larger	2.50

NORTONVILLE. Population, 638. Nortonville Electric Light, Power, and Heating Plant. Maximum rate, 15c per kw-hr. Minimum monthly charge, $1.50.

OAKLEY. Population, 681. Municipal Water and Light Plant. Circuits: Night lighting circuit, 110 v., 60 cycles. Number of customers, 115.

STREET LIGHTING:

40 Mazda type C lamps, 60 c. p., no charge. City furnishes renewals.

COMMERCIAL LIGHTING:

From 5 to 25 kw-hrs. per month	12.5c. per kw-hr.
All above 25 kw-hrs. per month	10c. per kw-hr.

Minimum rate, 75c. per month.

OGDEN. Population, 230. (See Home).

OKETO. Population, 253. Municipal Electric Light Plant. Circuits: Night lighting, d. c., 110 v.

STREET LIGHTING:

16 incandescent 150-watt lamps, $18 each per year. City furnishes renewals.

COMMERCIAL LIGHTING:

Meter rate, 15c. per kw-hr. Flat rate, 1c. per watt.
Minimum rate, $1 per month.

OLATHE. Population, 3272. Olathe Electric Light and Power Company. Circuits: Day and night lighting, 110 v. Day and night motor, 220 v. Number of customers, 390.

STREET LIGHTING:

27 arcs 6.6 amps., moonlight schedule	$66 each per year.
83 incandescents, 100 c. p., moonlight schedule	18 each per year.

Company furnishes renewals.

COMMERCIAL LIGHTING:

Meter rates: On contract with special minimum 8c. per kw-hr., for first 30 hours use of lamp per lamp per month; balance 5c. per kw-hr.

Flat rates: A very few: strictly office rooms, $5 per 60-watt lamp per year, payable in advance. Halls, 75c. per month, all-night service. Have only 3 or 4 in town.

Minimum rate: Commercial, $1; residence, 75c.

COMMERCIAL POWER:

First 300 kw-hrs	5c. per kw-hr.
Next 200 kw-hrs	4c. per kw-hr.
All over	3c. per kw-hr.

Minimum rate: ½ to 1 hp., $1.50 per month; 2 hp. and over, $1 per hp. per month; less than ½ hp. on lighting minimum.

Meters are furnished by the company without any deposit.

A penalty of 10 per cent is added to bills not paid by the tenth of the month.

ONAGA. Onaga Light, Heat and Power Company. Circuits: Day and night lighting, and motor circuits, 220 v., d. c. Number of customers, about 125.

STREET LIGHTING:

43 series 6.6-amp., 75-watt lamps, moonlight schedule, $15.75 per year each. Renewals are furnished by the plant. Contract calls for: all the light that is necessary except between the hours of 12 midnight and 5 a. m.

COMMERCIAL LIGHTING:

Meter rates:

1 to 35 kw-hrs. at	12c. per kw-hr.
36 to 50 kw-hrs	11c. per kw-hr.
51 to 200 kw-hrs	10c. per kw-hr.
201 to 300 kw-hrs. at	9c. per kw-hr.
301 to 450 kw-hrs. at	8c. per kw-hr.
451 to 550 kw-hrs. at	7c. per kw-hr.
More than 550 kw-hrs. at	6c. per kw-hr.

Based on monthly consumption by each customer's meter.

Minimum rates: From October 1 to April 1, $1.50 per month; from April 1 to October 1, 75c.

Power rates: None except as listed under lighting.

Meters are rented at 25c. per month, half of which is applied to the payment of the meter, or meters are sold outright at cost and kept in repair.

OSAGE CITY. Population, 2432. Municipal Electric Light Plant. Maximum rate, 12c per kw-hr. Minimum monthly charge, 50c. 2 per cent discount for prompt payment.

OSBORNE. Population, 1566. Municipal Light and Power Plant. Circuits: a. c., lighting, 110 v., 60 cycles. Number of customers, 240.

STREET LIGHTING:

62 series, 5.5 amp., 100, 200 and 350-watt lamps, moonlight schedule; total per year, $1,000 .

COMMERCIAL LIGHTING:

Meter rate: 12, 10 and 8c. according to amount used; 7c. for all over 100 kw-hrs. per month.

Flat rate: 50c., 75c., $1.00 and $1.25, covering lamps from 25 to 100 watts. No flat rate on larger sizes.

Minimum rate, $1 per month.

COMMERCIAL POWER:

8.5c. for first 100 kw-hrs. then lowers to 4c. according to the amount used.

Meters are furnished by the city and minimum includes the meter rent.

OSKALOOSA. Population, 851. Moxley and Company. Circuits: Day and night lighting at 110 v., a. c., Day and night motor series, a. c. Number of customers, 230.

STREET LIGHTING:

12 Type C, 250 c. p. lamps, midnight schdule; 55 type C, 60 c. p. lamps, moonlight schedule; total, $95 per month. Renewals are furnished by the city.

COMMERCIAL LIGHTING:

Meter rates: Minimum, $1.50.

0 to 15 kw-hrs. at	15c. per kw-hr.
16 to 20 kw-hrs. at	14c. per kw-hr.
21 to 30 kw-hrs. at	13c. per kw-hr.
31 to 40 kw-hrs. at	12c. per kw-hr.
41 to 50 kw-hrs. at	11c. per kw-hr.
51 to 100 kw-hrs. at	10c. per kw-hr.
100 and up	9c. per kw-hr.

Flat rates:

1 16 c. p. carbon lamp per month	$0.70
2 16 c. p. carbon lamps per month	1.35
3 16 c. p. carbon lamps per month	1.95

All other sizes figured on the same basis.

1 40-watt tungsten lamp per month	$0.60
2 40-watt tungsten lamps per month	1.10
3 40-watt tungsten lamps per month	1.50
1 60-watt tungsten lamp per month	0.90
2 60-watt tungsten lamps per month	1.65
3 60-watt tungsten lamps per month	2.20
1 100-watt tungsten lamp per month	1.15
2 100-watt tungsten lamps per month	2.00
3 100-watt tungsten lamps per month	2.85

All over 3 lamps will come under the meter schedule.

OTTAWA. Population, 7700. Municipal Light and Water Plant. Circuits: a. c., day and night lighting and motor circuit, 110 v. Number of customers, 650.

STREET LIGHTING:

200 type C 100 c. p. lamps, all-night, moonlight schedule; 90 series, 15 amp., 400 c. p., white-way lights. New lights are now being installed and the rates are not yet determined upon. Water and light department furnishes renewals.

COMMERCIAL LIGHTING:

Meter rates:

50 kw-hrs. for $4, next 100 kw-hrs. at	6c. per kw-hr.
150 kw-hrs. for 10, next 150 kw-hrs. at	4c. per kw-hr.
300 kw-hrs. for 16, next 200 kw-hrs. at	2c. per kw-hr.
500 kw-hrs. for 20, 500 and over at	4c. per kw-hr.

Monthly minimum charge, 50c.

COMMERCIAL POWER:

For customers who use electricity for power or heating purposes at times other than during the "peak-load" hours specified in the ordinance and who accept the provisions of a "power contract" limiting the service as provided, the following power rates shall be in effect:

For the first 100 kw-hrs	7c. per kw-hr.
For the next 100 kw-hrs	4c. per kw-hr.
For the next 800 kw-hrs	3c. per kw-hr.
All in excess of 1,000 kw-hrs	2.5c. per kw-hr.

The minimum bill for any polyphase service is $2, and the right is reserved to charge a larger minimum based on the connected load, but not to exceed $1 per hp.

Power rates may be granted to consumers who require not more than 10 per cent of their electricity during the peak hours, provided the right is reserved to install two-rate meters and charge regular lighting rates for the electricity used during the peak hours. All power contracts shall provide, the right is reserved to prohibit the connecting or use of any electric lights on power services.

The peak-load hours during which the use of electricity under power contracts is restricted, shall be from 5 p. m. to 10 p. m., during the months of November, December, January and February; from 6 p. m. to 10 p. m., during the months of March, April and September and October, and from 7 p. m. to 10 p. m. during the months of May, June, July and August.

Special rates:

A rate of 4c. per kw-hr. may be granted for cooking service, subject to a minimum charge of $1 per month and shall not be used for any other purpose.

Meters are furnished by the company.

No discounts are given, but a penalty of 10 per cent is added if bill is not paid by the tenth of the month.

PALMER. Population, 400. (See Aurora.)

PARSONS. Population, 12,500. Parsons Railway and Light Company.

STREET LIGHTING:

124 600 c. p. lamps, all-night schedule	$65 per year.
13 400 c. p. lamps, all-night schedule	60 per year.

Renewals by the company.

LIGHTING RATES:

Residence:

1 to 20 kw-hrs	10c. per kw-hr.
20 to 40 kw-hrs	7c. per kw-hr.
All over 60 kw-hrs	4c. per kw-hr.

Business:

1 to 50 kw-hrs	10c. per kw-hr.
Next 100 kw-hrs	7c. per kw-hr.
All over 150 kw-hrs	4c. per kw-hr.

POWER RATES:

1 to 80 hours use per month of demand	$0.06 per kw-hr.
81 to 90 hours use per month of demand	.056 per kw-hr.
91 to 100 hours use per month of demand	.0527 per kw-hr.
101 to 110 hours use per month of demand	.0497 per kw-hr.
111 to 120 hours use per month of demand	.0472 per kw-hr.
121 to 130 hours use per month of demand	.0452 per kw-hr.
131 to 140 hours use per month of demand	.0434 per kw-hr.
141 to 150 hours use per month of demand	.0419 per kw-hr.
151 to 160 hours use per month of demand	.0406 per kw-hr.
161 to 170 hours use per month of demand	.0397 per kw-hr.
171 to 180 hours use per month of demand	.039 per kw-hr.
181 to 190 hours use per month of demand	.0384 per kw-hr.
191 to 200 hours use per month of demand	.038 per kw-hr.
201 to 210 hours use per month of demand	.0375 per kw-hr.
211 to 220 hours use per month of demand	.0371 per kw-hr.
221 to 230 hours use per month of demand	.0367 per kw-hr.
231 to 240 hours use per month of demand	.0362 per kw-hr.
241 to 250 hours use per month of demand	.0355 per kw-hr.
251 to 260 hours use per month of demand	.0354 per kw-hr.
261 to 270 hours use per month of demand	.0350 per kw-hr.
271 to 280 hours use per month of demand	.0346 per kw-hr.
281 to 290 hours use per month of demand	.0342 per kw-hr.
291 to 300 hours use per month of demand	.0338 per kw-hr.

A discount of 10 per cent is allowed if bill is paid on or before the tenth of the month.
Minimum charge of 50c. per hp. per month; minimum charge on lighting is 75c. pei month

PEABODY. Population, 1415. Peabody Light, Power and Ice Company.

STREET LIGHTING:

73 series Mazda lamps, 60 c. p., moonlight schedule	$15 per year.
4 500-watt arcs, all night, moonlight schedule	90 per year.
4 100-watt series, Mazda lamps, all-night schedule	36 per year.

PERRY. Population, 500. Municipal Light Plant.

STREET LIGHTING:

35, 60 and 80-watt lamps, moonlight schedule, $600 per year.

LIGHTING RATES: 10c. per kw-hr.

No power consumers. Minimum, $1 per month.
No discount, but a penalty of 10 per cent is added if not paid by the tenth of the month.

PHILLIPSBURG. Population, 1302. Phillipsburg Mill and Elevator Company. Maximum rate, 15c per kw-hr., with 10 per cent discount for prompt payment.

PITTSBURG (FRONTENAC AND CHEROKEE). Population, 14,750 Kansas Gas and Electric Company. Number of customers, 2033.

STREET LIGHTING. (Pittsburg only):

100 arcs, 6.6 amp., 500-watt lamps, all-night schedule	$84 each per year.
70 arcs, 6.6 amp., 500-watt lamps, all-night schedule	78 each per year.
346 Tungsten 100-watt lamps, midnight schedule	11 per pole pei year.
173 Tungsten 80-watt lamps, all-night schedule	14 per pole per year.

The high franchise rate of $84 per year has been offset by low rate on ornamental street lighting system of $18 per 3-light pole per year. Company furnishes renewals.

RESIDENTIAL AND COMMERCIAL LIGHTING. (Pittsburg and Frontenac):

Meter rate:

For first 50 kw-hrs. per month	10c. per kw-hr.
For next 25 kw-hrs. per month	9c. per kw-hr.
For next 25 kw-hrs. per month	5c. per kw-hr.
For next 100 kw-hrs. per month	4½c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 400 kw-hrs. per month	3½c. per kw-hr.
For next 400 kw-hrs. per month	3¼c. per kw-hr.
For all over 1,200 kw-hrs. per month	4c. per kw-hr.

Minimum monthly charge, $1.

INDUSTRIAL POWER:

Meter rate:

For first 50 kw-hrs. per month	10c. per kw-hr.
For next 25 kw-hrs. per month	[illegible]c. per kw-hr.
For next 25 kw-hrs. per month	5c. per kw-hr.
For next 100 kw-hrs. per month	4½c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 400 kw-hrs. per month	3½c. per kw-hr.
For next 400 kw-hrs. per month	3½c. per kw-hr.
For all over 1,200 kw-hrs. per month	4c. per kw-hr.

Minimum monthly charge, $1.

RESIDENTIAL AND COMMERCIAL LIGHTING. (Cherokee only):

Meter rate:

For first 30 kw-hrs. per month .... 13c. per kw-hr.
For next 60 kw-hrs. per month .... 11c. per kw-hr.
For next 120 kw-hrs. per month .... 10c. per kw-hr.
All over 210 kw-hrs. per month .... 9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.
Monthly minimum charge for lighting service, $1.

ADVERTISING LIGHTING. (Frontenac and Cherokee):

Flat rate: Consisting of sign, outline, display, window and spectacular lighting. Burning from dusk until midnight, every night, under power company control.

Per watt rated capacity of connected load per month, 1c. net.

Minimum monthly charge, $1.

INDUSTRIAL POWER. (Customer's option):

$1.50 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as follows:

For first 100 kw-hrs. per month .... 7c. per kw-hr.
For next 100 kw-hrs. per month .... 6c. per kw-hr.
For next 100 kw-hrs. per month .... 5c. per kw-hr.
For next 200 kw-hrs. per month .... 4c. per kw-hr.
For next 1,000 kw-hrs. per month .... 3c. per kw-hr.
For next 3,500 kw-hrs. per month .... 2c. per kw-hr.
For next 10,000 kw-hrs. per month .... 1c. per kw-hr.
For next 20,000 kw-hrs. per month .... 7 mills per kw-hr.
All over 35,000 kw-hrs. per month .... 6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

For twenty-hour off-peak service: $1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

The customer will be required to furnish a time switch for off-peak service.

INDUSTRIAL POWER. (Pittsburg and vicinity only):

A net rate of 3c. per kw-hr., with a minimum guarantee of $1 per hp. of connected load per month.

NOTE.—This rate has been given chiefly to coal mines in Pittsburg and vicinity, which are of necessity off-peak customers.

PLAINVILLE. Population, 1090. Plainville Mill and Elevator Company.

STREET LIGHTING:

36 6.6 amp., 250-watt lamps, moonlight schedule, excepting out from 12 to 4 a. m., $30 per year. Renewals by the company.

LIGHT AND POWER RATES:

Less than 100 kw-hrs .... 10c. per kw-hr.
Over 100 and less than 150 kw-hrs .... 9c. per kw-hr.
Over 150 and less than 200 kw-hrs .... 8c. per kw-hr.
Over 200 and less than 250 kw-hrs .... 7½c. per kw-hr.
Over 250 and less than 300 kw-hrs .... 7c. per kw-hr.
Over 300 and less than 350 kw-hrs .... 6½c. per kw-hr.
Over 350 and less than 400 kw-hrs .... 6c. per kw-hr.
Over 400 and less than 500 .... 5c. per kw-hr.
Over 500 kw-hrs .... 5c. per kw-hr.

Minimum rate is $1 per month.
Meters are rented to customer at 25c. per mouth.

PRETTY PRAIRIE. Population, 330. Pretty Prairie Light and Power Company.

STREET LIGHTING:

6 6.6 amp. arcs, 1,200 watts, moonlight schedule .... $75 per year.
12 Mazda, 100-watt lamps, moonlight schedule .... 24 per year.

LIGHT AND POWER RATES: 15c. per kw-hr. straight.

Minimum, 75c. per month.
No discount.

RANDOLPH. Population, 325. (See Burr Oak).

REBECCA. (See Home).

REPUBLIC CITY. Population, 450. (See Burr Oak.)

RUSSELL. Population, 1700. Municipal Light Plant.

STREET LIGHTING:

42 6.6-amp., 100-watt lamps, moonlight schedule, and 8 6.6-amp., 420-watt arc lamps, moonlight schedule paid by city fund.

LIGHTING RATES:

First 20 kw-hrs	12½c. per kw-hr.
Next 20 kw-hrs	10c. per kw-hr.
All over 40 kw-hrs	8c. per kw-hr.

POWER RATES:

First 500 kw-hrs	5c. per kw-hr.
Next 1,000 kw-hrs	4c. per kw-hr.
All above 1,500 kw-hrs	3c. per kw-hr.

For range cooking 3c. per kw-hr. straight.

Minimum rate, $1 per month.

Meters are owned by consumers except in a few instances where meters are rented for 25c. per month.

There is no discount, but a penalty of 10 per cent is added if bill is not paid by the tenth of the month.

SALINA. Population, 9688. Salina Light, Power and Gas Company.

STREET LIGHTING:

135 6.6-amp. lamps, all-night schedule, $72 and $60 per year; 23 60 c. p., series tungsten lamps, all-night schedule, $24 per year. Lamp renewals by the company.

LIGHTING RATES:

First 20 kw-hrs	12c. per kw-hr.
Next 30 kw-hrs	10c. per kw-hr.
All over 50 kw-hrs	5c. per kw-hr.

POWER RATES:

First 400 kw-hrs	5c. per kw-hr.
Next 200 kw-hrs	4½c. per kw-hr.
Next 200 kw-hrs	4c. per kw-hr.
Next 200 kw-hrs	3½c. per kw-hr.
All over 1,000 kw-hrs	3c. per kw-hr.

Minimum, $1 per month.

Ten per cent discount if paid by the tenth of the month. This applies to power and lighting equally.

Minimum of $1 per hp.

A new rate schedule is being worked out and will go into effect the summer of 1916.

SCANDIA. Population, 579. (See Burr Oak).

SCOTT CITY. Population, 918. Municipal Light and Water Plant.

STREET LIGHTING:

72 40-watt Mazda lamps, midnight schedule	$8.40 per year.
64 25-watt Mazda lamps, midnight schedule	5.40 per year.
4 60-watt Mazda lamps, all-night schedule	Free.

Lamp renewals are furnished by the plant.

COMMERCIAL LIGHTING:

First 8 kw-hrs	12½c. per kw-hr.
All over 8 kw-hrs	10c. per kw-hr.

Minimum monthly charge, $1.

Meters are furnished by the city.

SEDAN. Population, 2220. Sedan Electric Light and Power Company.

STREET LIGHTING:

2 350-c. p. Mazda series lamps, moonlight schedule	$31.12 per year each.
12 200-c. p. series Mazda lamps, moonlight schedule	18.68 per year each.

Renewals by the company.

LIGHTING RATES:

First 25 kw-hrs	10c. per kw-hr.
All over 25 kw-hrs	8c. per kw-hr.

POWER RATES:

$5 per hp. per month for peak-load power. $3 per hp. per month for balance of time.

Minimum rate, 50c. per month.

Customers own meters. There are no discounts.

SEDGWICK. Population, 626. (See Halstead).

SMITH CENTER. Population, 1292. Smith Center Mill, Elevator and Light Company. Maximum rate, 15c per kw-hr.

SOUTH HAVEN. Population, 486. South Haven Municipal Electric Light Plant.

STREET LIGHTING:

35 4-amp., 80-c. p., lamps, moonlight schedule, $18 per year.

LIGHTING RATES:

14c. per kw-hr., graded down to 9c. according to amount used.
Minimum of $1 for business houses and 75c. for residences.
Discount of 10 per cent for prompt payment.

STERLING. Population, 2133. Morris Electrical Power Company. Maximum rate, 15c per kw-hr.

STOCKTON. Population, 1400. Municipal Electric Light Plant.

STREET LIGHTING:

90 series tungsten 5.5-amp., 60-c. p. lamps, midnight schedule, paid by plant itself.

LIGHTING RATES:

10c. per kw-hr. up to 1,000 kw-hrs. Over 1,000 kw-hrs., 7c.

POWER RATES:

Motors, 7c. per kw-hr. up to 5. hp. Over 5 hp. 6c. per kw-hr.
Cooking stoves, 6c. per kw-hr.
Minimum on stoves, $1 per month.
Minimum on motors, over 5 hp., $1; under 5 hp., 50c.
Minimum lighting rate, 40c. per month.

SYRACUSE. Population, 1125. Syracuse Water and Light Plant.

STREET LIGHTING:

63 6.6-amp., 100-watt lamps, moonlight schedule, $30 per year.

LIGHTING RATES:

1 to 50 kw-hrs	10c. per kw-hr.
Over 50 kw-hrs	8c. per kw-hr.

Power rate is the same as the lighting rates.
Minimum, $1 per month.
There is no discount.

TONGANOXIE. Population, 1020. Barber-Angell Electric Light Company

STREET LIGHTING:

65 40-watt lamps, midnight schedule	$8.50 per year.
8 100-watt lamps, midnight schedule	21.00 per year.

Renewals by the company.

LIGHTING RATES: 12c. per kw-hr. Power rate is the same.

Discount of 2 per cent on prompt payment of bills.
Monthly minimum, 50c.

TOPEKA. Population, 50,000.

MUNICIPAL ELECTRIC LIGHTING PLANT. This plant is a municipal plant doing street lighting service only.

STREET LIGHTING—

473 arcs, 4 amp., 272 watts, moonlight after midnight schedule, $38.15 each.
24 incandescent series, 4 amp., 280-watt lamps, moonlight after midnight schedule, $34.62 each.
283 incandescent series, 4-amp., 80-watt lamps, moonlight after midnight schedule, $22.30 each.
346 incandescent multiple, 100-watt lamps, after midnight moonlight schedule, $12.07 each.
1,236 incandescent multiple, 60-watt lamps, moonlight after midnight schedule, $5.67 each.
The above rates are the total costs per year, including the overhead charges.
Renewals are furnished by the plant.

TOPEKA EDISON COMPANY:

Residence lighting rate	7c. per kw-hr., net rate.
Commercial lighting and small power:	
1 to 150 kw-hrs. per month	7c. per kw-hr., net rate.
150 to 200 kw-hrs. per month	6c. per kw-hr., net rate.
Over 200 kw-hrs. per month	5c. per kw-hr., net rate.

With a maximum bill at any rate not to exceed the first step in the next lower rate.

Electric elevator service:

First 350 kw-hrs. per month	7c. per kw-hr., net rate.
Excess	5c. per kw-hr., net rate.

Church lighting, assembly rooms, etc.:

First 250 kw-hrs. per month	7c. per kw-hr., net rate.
Excess	5c. per kw-hr., net rate.

Wholesale rate for mixed lighting and power for department stores, etc.:

First 2,000 kw-hrs. per month	5c. per kw-hr., net rate.
Next 2,000 kw-hrs. per month	4c. per kw-hr., net rate.
Excess	3c. per kw-hr., net rate.

Battery auto charging rates same as commercial lighting and small power rates except on customers guaranteeing an annual minimum of $48, all current at 5c. per kw-hr., adjustment to be made at the end of year.

All of the above subject to a 10 per cent penalty with a minimum penalty of 25c. if not paid by the tenth of the month for the preceeding month's supply. The minimum bill for each meter installed is 40c. per month.

SCHEDULE OF POWER RATES:

Installations 1 to 5 hp.:

Less than 150 kw-hrs	7c. per kw-hr.
150 to 200 kw-hrs	6c. per kw-hr.
200 or over, kw-hrs	5c. per kw-hr.

Installations 6 to 10 hp.:

Guaranteeing $1.00 per hp. of connected load	4½c. per kw-hr.
Guaranteeing $1.50 per hp. of connected load	4c. per kw-hr.

Installations 11 to 30 hp., 70 per cent of connected load considered active; minimum active load, 10 hp.:

Guaranteeing $1.00 per hp. of active load	4½c. per kw-hr.
Guaranteeing $1.25 per hp. of active load	4c. per kw-hr.
Guaranteeing $1.50 per hp. of active load	3½c. per kw-hr.
Guaranteeing $2.25 per hp. of active load	3c. per kw-hr.

Installations 31 to 50 hp., 60 per cent of connected load considered active; minimum active load, 21 hp.:

Guaranteeing $1.00 per hp. of active load	4½c. per kw-hr.
Guaranteeing $1.25 per hp. of active load	4c. per kw-hr.
Guaranteeing $1.50 per hp. of active load	3½c. per kw-hr.
Guaranteeing $2.25 per hp. of active load	3c. per kw-hr.
Guaranteeing $3.25 per hp. of active load	2½c. per kw-hr.

Installations 50 hp. or over, 50 per cent of connected load considered active, but minimum active load, 30 hp.:

Guaranteeing $1.00 per hp. of active load	4½c. per kw-hr.
Guaranteeing $1.25 per hp. of active load	4c. per kw-hr.
Guaranteeing $1.50 per hp. of active load	3½c. per kw-hr.
Guaranteeing $2.25 per hp. of active load	3c. per kw-hr.
Guaranteeing $3.25 per hp. of active load	2½c. per kw-hr.
Guaranteeing $4.40 per hp. of active load	2c. per kw-hr.

Active load represents the maximum demand as shown by chart or demand meter placed on load and taken at intervals.

Any measurements of a demand in excess of originally estimated demand as shown by future measurements to be taken as active horsepower.

All customers signing a contract to keep off peak between the hours of 4:30 p. m. to 8:30 p. m. a discount of ½c. per kw. will be made.

TOWANDA. Population, 275. (See Benton).

VALLEY CENTER. Population, 381. (See Halstead).

VINING. Population, 191. (See Aurora).

WAMEGO. Population, 1750. Municipal Light and Water Company.

STREET LIGHTING:

91 type C, 6.6-amp. lamps, 100 watts, midnight schedule	$6 per year.
7 enclosed arc lamps, 550 watts, midnight schedule	40 per year.

Renewals by the light and water department.

LIGHTING RATES: 10c. pr kw-hr. straight.

POWER RATES:

6c. per kw-hr. with minimum bill of	$3.
5c. per kw-hr. with minimum bill of	6.
4c. per kw-hr. with minimum bill of	10.
3c. per kw-hr. with minimum bill of	20.

Minimum lighting bill, 50c. per month.
Meters are owned by the light and water department.
There are no discounts.

WASHINGTON. Population, 1547. (See Aurora).

WATHENA. Population, 780. Municipal Light Plant. Energy is purchased from St. Joseph, Mo.

STREET LIGHTING:

32 Mazda series lamps, 3.5 amp., 100 watts, moonlight schedule, 10c. per kw-hr., flat rate.

LIGHTING RATES: 12c. per kw-hr. straight with 10 per cent discount.

POWER: 7c. for first 250 kw-hrs., 6c. for second 250 kw-hrs., and 5c. for all over 500 kw-hrs. Monthly minimum, 75c.

WAVERLY. Population, 750. Municipal Light and Water Company.

STREET LIGHTING:

22 6.6-amp., 100-c. p. lamps, moonlight schedule	$1.50 per month each.
4 6.6-amp., 250-c. p. lamps, moonlight schedule	1.50 per month each.

LIGHTING AND POWER RATES:

1 to 10 kw-hrs. per month	15c. per kw-hr.
11 to 20 kw-hrs. per month	14c. per kw-hr.
21 to 30 kw-hrs. per month	13c. per kw-hr.
31 to 40 kw-hrs. per month	12c. per kw-hr.
41 to 50 kw-hrs. per month	11c. per kw-hr.
51 and over of kw-hrs. per month	10c. per kw-hr.

Flat rates: 1 lamp, 60c. per month; 2 lamps, 50c. per month each; 3 or more lamps, 40c. per month each.

Meters are owned by the city. If current consumed amounts to less than $1 per month, a 15c. rental is charged; if over $1, there is no rental.

There is no discount.

WELLINGTON. Population, 7050. Municipal Light Plant.

STREET LIGHTING:

60 6.6-amp. arcs, all-night moonlight schedule; 100 6.6 amp., series Mazda lamps, all-night moonlight schedule; street lighting paid for by a .4 mill tax.

POWER AND LIGHTING RATES:

8c. per kw-hr. with the following discounts:

10 to 30 kw-hrs	5 per cent.
30 to 50 kw-hrs	10 per cent.
50 to 70 kw-hrs	15 per cent.
70 to 100 kw-hrs	20 per cent.
100 and over	25 per cent.

Motor rate runs from 2¾c. to 5c., based on quantity.
There is no meter rental, but a deposit of $6 is required.
Minimum rate is 50c. per month.

WELLSVILLE. Population, 650. Wellsville Light, Power and Ice Company.

STREET LIGHTING RATES:

17 Mazda type C 250-c. p. lamps, and 46 Mazda type C 100-c. p. lamps; all lamps burned 150 hours per month for total of $78 per month. Additional hours at 25c. per hour. The monthly average is about 170 hours. Lamp renewals by company.

COMMERCIAL LIGHTING RATES: 10c. per kw-hr., all over 50 kw-hrs., at 5c.

POWER RATES:

First 50 kw-hrs	10c. per kw-hr.
Next 500 kw-hrs	5c. per kw-hr.
Next 750 kw-hrs	4c. per kw-hr.
All over 1,300 kw-hrs	3c. per kw-hr.

Minimum rate is 50c. with $5 deposit or $1 without deposit.
Company owns all meters. There is no discount.

WETMORE. Population, 600. Municipal Light Plant.

STREET LIGHTING RATES:

32 series Mazda lamps, 6.6 amp., 100 and 250 c. p., moonlight schedule, $35 per lamp per year.

COMMERCIAL LIGHTING RATES:

10c. per kw-hr. straight.
Meter rental, 25c. per month.
Flat rate of 50c. per month for two lamps.
There are no discounts and no power rates.

WICHITA. Population, 70,000. Kansas Gas and Electric Company. Number of customers, 7975.

STREET LIGHTING:

47 arc lamps, 4 amp., 375 watts, all-night schedule	$64 each per year.
235 arc lamps, 4 amp., 375 watts, all-night schedule	35 each per year.
63 arc lamps, 4 amp., 375 watts, all-night schedule	64 each per year.
23 tungsten lamps, 100 watts, all-night schedule	16 each per year.
113 tungsten lamps, 100 watts, midnight schedule	10.60 each per year.
1,200 tungsten lamps, 80 watts, all-night schedule	16 each per year.

Renewals are furnished by the company.

RESIDENTIAL LIGHTING:

12½c. per kw-hr., with a discount of 20 per cent for payment within fifteen days after date of billing.

Minimum monthly charge, $1.

COMMERCIAL LIGHTING. (Based on connected load):

Meter rate: In computing size of connected load for billing purposes, 100 per cent of the actual connected load between 0 and 2.5 kilowatts will be considered active; 75 per cent of the actual connected load between 2.5 kilowatts and 5 kilowatts will be considered active, and 50 per cent of the actual connected load over 5 kilowatts will be considered active.

First 30 kw-hrs. per kilowatt of connected load per month, 10c. per kw-hr.

Next 30 kw-hrs. per kilowatt of connected load per month, 7c. per kw-hr.

All in excess of 60 kw-hrs. per kilowatt of connected load per month, 4c. per kw-hr.

Less 10 per cent discount if paid within fifteen days after date of billing.

Minimum monthly charge, $1.

ADVERTISING LIGHTING. (Flat rate):

Consisting of sign, outline, display window and spectacular lighting. Burning from dusk until midnight, every night, under power company control.

Per watt rated capacity of connected load per month, 1c. net.

Where lamp renewals are furnished, an addition of 4c. per watt.

Monthly minimum charge, $1.

INDUSTRIAL POWER:

Meter rate:

First 100 kw-hrs. per month	8c. per kw-hr., net.
Next 100 kw-hrs. per month	6c. per kw-hr., net.
Next 100 kw-hrs. per month	5c. per kw-hr., net.
Next 200 kw-hrs. per month	4c. per kw-hr., net.
All over 500 kw-hrs. per month	3½c. per kw-hr., net.

Minimum monthly charge, $1.

INDUSTRIAL POWER. (Customer's option):

Meter rate:

First 100 kw-hrs. per month	8c. per kw-hr., net.
Next 100 kw-hrs. per month	6c. per kw-hr., net.
Next 100 kw-hrs. per month	5c. per kw-hr., net.
Next 200 kw-hrs. per month	4c. per kw-hr., net.
Next 1,000 kw-hrs. per month	3½c. per kw-hr., net.
Next 3,500 kw-hrs. per month	3c. per kw-hr., net.
All over 5,000 kw-hrs. per month	2½c. per kw-hr., net.

Monthly minimum charge, 50c. per hp.

INDUSTRIAL POWER. (Customer's option):

Meter rate: (For continuous service):

$1.50 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as follows:

For first 100 kw-hrs. per month	7c. per kw-hr.
For next 100 kw-hrs. per month	6c. per kw-hr.
For next 100 kw-hrs. per month	5c. per kw-hr.
For next 200 kw-hrs. per month	4c. per kw-hr.
For next 1,000 kw-hrs. per month	3c. per kw-hr.
For next 3,500 kw-hrs. per month	2c. per kw-hr.
For next 10,000 kw-hrs. per month	1c. per kw-hr.
For next 20,000 kw-hrs. per month	7 mills per kw-hr.
All over 35,000 kw-hrs. per month	6 mills per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

For twenty-hour off-peak service:

$1.10 fixed charge per kilowatt connected load or maximum demand per month, plus an energy charge as shown above.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

The customer will be required to furnish a time switch for off-peak service.

RURAL DOMESTIC LIGHTING AND POWER:

Meter rate: To apply in the territory adjacent to and outside of the corporate limits of Wichita.

For first 30 kw-hrs. per month	13c. per kw-hr.
For next 60 kw-hrs. per month	11c. per kw-hr.
For next 120 kw-hrs. per month	10c. per kw-hr.
All over 210 kw-hrs. per month	9c. per kw-hr.

Less a discount of 10 per cent if paid within fifteen days from date of billing.

Minimum monthly charge for lighting service, $1.

Minimum monthly charge for power service, $1.

WILDCAT. (See Home).

WINFIELD. Population, 8000. Municipal Light, Power and Water Plant.

STREET LIGHTING RATES:

20 C Mazda lamps, 300 watts; 90 560-watt arc lamps; all are burned until 12:30 a. m., moonlight schedule; no charge.

LIGHTING RATES:

1 to 25 kw-hrs. at	10c.	26 to 27 kw-hrs., total	$2.50
28 to 50 kw-hrs., at	9c.	51 to 56 kw-hrs., total	4.50
57 to 75 kw-hrs., at	8c.	76 to 85 kw-hrs., total	6.00
86 to 100 kw-hrs., at	7c.	101 to 115 kw-hrs., total	7.00
116 to 125 kw-hrs., at	6c.	126 to 150 kw-hrs., total	7.50
150 and over, at	5c.		

Minimum charges:

5-ampere meter	$0.50 per month.
10-ampere meter	1.00 per month.
15-ampere meter	2.00 per month.
20-ampere meter	2.50 per month.

POWER RATES:

1 to 800 kw-hrs., at	5c.	801 to 1,000 kw-hrs., total	$40.00
1,001 to 2,000 kw-hrs., at	4c.	2,001 to 2,285 kw-hrs., total	80.00
2,286 to 2,858 kw-hrs., at	3½c.	2,859 to 3,333 kw-hrs., total	100.00

3,334 and over per month, at 3c. per kw-hr.

Minimum charges:

½ to 2 hp. per month	$1.00
2 to 5 hp. per month	2.00
5 to 10 hp. per month	3.00
All over 10 hp	5.00

Rebate of 10 per cent on all bills except minimums if paid before the tenth of the month.

A deposit of $2.50 is required for a meter installation in a residence and $5 for a meter installation in a business house.

YATES CENTER. Population, 2024. Yates Center Electric Light and Power Company. Maximum rate, 12½c per kw-hr.

BULLETIN OF THE UNIVERSITY OF KANSAS.

VOL. 18. DECEMBER 1, 1917. No. 18.

BULLETIN No. 2.

DIVISION OF STATE CHEMICAL RESEARCH.

W. A. WHITAKER, *Director*.

SEWAGE DISPOSAL IN KANSAS:

A Discussion of Practice in Certain Municipalities. Together with Instructions to Plant Operators.

BY

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With the collaboration of the Division of Water and Sewage, Kansas State Board of Health.

C. A. HASKINS, *Engineer*.
C. C. YOUNG, *Director of Laboratory*.

ENGINEERING BULLETIN No. 9.

Entered as second-class matter December 29, 1910, at the postoffice at Lawrence, Kansas, under the act of July 16, 1894.

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THE DIVISION OF STATE CHEMICAL RESEARCH.

UNIVERSITY OF KANSAS.

Included in the Department of Chemistry of the University of Kansas is the Division of State Chemical Research, which has for its object the study of those problems of Kansas, municipal or industrial, which may lend themselves to chemical investigation. In addition to its own problems, this division coöperates with other University activities which are engaged in state service work.

The following problems have been studied, or are now in process of investigation:

The Removal of Iron from Municipal Water Supplies.
Sewage Disposal in Kansas.
The Natural Gases of the Mid-Continent Field.
The Physical and Chemical Properties of Kansas Petroleums.
The Coals of Kansas.
The Salt Industry in Kansas.
A Search for Potash in Kansas.
The Conservation of Mineral Wastes by Flotation.
The Softening of Hard Waters.

Correspondence regarding these investigations should be addressed to the Director, Division of State Chemical Research.

TABLE OF CONTENTS.

SEWAGE DISPOSAL IN KANSAS.

PREFACE.

THE investigation upon which this bulletin is based was undertaken with the object of determining:

(1) The extent of purification that is actually being effected by the sewage disposal plants in Kansas.
(2) The methods for improving the operation of these plants.
(3) The amount of work that may be expected of them.

It was undertaken with the additional object of supplying to the plant operator a handbook which would set forth the following:

(1) Some of the underlying principles of sewage disposal.
(2) Detailed instruction in the operation of certain plants.
(3) Data on the operation of a few representative Kansas plants.
(4) Instruction in the making of simple tests and the uses of these as indicators in plant operation.

In addition to this it was desired to arouse the interest of the communities which maintain disposal plants, and to emphasize the fact that a disposal plant is an important part of a city's property and should be treated as such.

It is true that many of our plants are doing very poor work, and it is the rule rather than the exception to find these plants in an exceedingly unsightly condition.

In nearly every case the cities themselves are to be blamed for this condition. Certainly the fault is not to be laid at the door of the designing engineer, who generally has embodied the latest developments of sewage disposal practice in the design of the plant; nor can the water superintendent or city engineer, who has direct charge of the plant, be censured for this, because he has other duties, which, while they are no more important than the control of the disposal plant, come more under his regular line of work. He finds time only for an occasional inspection trip, and it is unreasonable to expect him to spend enough time at the plant to insure its successful operation.

It is not the purpose of this bulletin to bring out anything new

in the way of methods of sewage disposal, nor even to go into detailed description of the many complex, physical, chemical and biological actions and reactions upon which the art of sewage disposal is based. The reader who wishes data on this phase of the subject is referred to one of several excellent textbooks on sewage disposal.

CHAPTER I.

INTRODUCTION.

RECOGNIZING the need of accurate data on the operation of the small sewage disposal plant, the Division of State Chemical Research of the University of Kansas devoted the services of two of its men for a period of two years to a study of the operation of eight representative Kansas sewage disposal plants. This bulletin is a report of this work.

The expenses of the investigation were borne by the Division of State Chemical Research, with the exception that part of the apparatus was furnished by the Division of Water and Sewage of the Kansas State Board of Health, and that the expense of livery for the use of the field man in the collection of samples was borne by the cities visited.

Plan of Work.

The general plan of work comprised the testing of several plants in rotation. The intention at first was that the field man should spend one week at each plant, but it was soon seen that this would not give sufficient time for a representative test, and the period was increased to two weeks for the first year. During the last year of the test the period was a month or more. This increase in length of tests allowed for a more accurate gauging of the conditions under which the plant operated and gave more weight to the results obtained.

The work was carried on by two men, one being in the field and the other in the laboratory. From time to time aid was given to the field man by the cities visited.

The program of work consisted of:

(1) Gauging the sewage flow, and in some cases the flow of the stream into which the treated sewage emptied.
(2) Collecting samples of sewage in different stages of treatment.
(3) Making field tests on same, and sending samples to the laboratory at Lawrence.
(4) Analyzing the samples at Lawrence.
(5) Collecting data on:
   - *a.* Operation of plants.
   - *b.* Accumulation of sludge.
   - *c.* Number of persons connected to sewer.
   - *d.* Leakage of ground or surface water into the system, etc.
   - *e.* General conditions of nuisance caused by the plant, etc.

(6) Publishing a bulletin setting forth the results of investigation.

Plants Chosen for the Investigation.

In choosing the plants for investigation, several points were considered: First, a good example of each type of plant in operation in the state was desired. Second, the plant should be located near enough to Lawrence so that a sample shipped one day could reach the laboratory in time for analysis on the day following. Third, plants should be situated in cities where help could be furnished the field man. The following plants were chosen:

(1) Burlingame. Imhoff tank with secondary treatment in contact beds.
(2) Osage City. Plain one-story septic tank with secondary treatment in contact beds.
(3) Newton. Plain one-story septic tank.
(4) State Home for the Feeble-Minded, Winfield. Imhoff tank with secondary treatment in contact beds and final treatment on sand filter.
(5) Cherryvale. Plain septic tank with contact beds.
(6) Independence. Plain septic tank with contact beds.
(7) Girard. Plain septic tank with contact beds.
(8) El Dorado. Plain septic tank with apparatus for sterilization by liquid chlorine.

Time Spent on Actual Tests.

The following table shows:

(1) The number of days spent in actual tests of the plants. This does not include time spent in setting up the portable laboratory or in moving from town to town.
(2) Number of samples taken.
(3) Number of tests made on samples in laboratory and in field.

Plant.	Number of days spent.	Samples taken.	Tests.	
			Laboratory.	Field.
Burlingame	25	225	600	1,125
Osage City	10	80	120	320
Newton	15	70	150	280
Winfield	40	360	720	1,800
Cherryvale	33	307	330	1,535
El Dorado	34	340	408	1,700
Girard	9	81	90	405
Total	166	1,463	3,128	7,165

Method of Investigation.

FIELD TESTS.

The following determinations were made in the field:

(1) Dissolved oxygen on raw sewage, septic tank effluent and contact bed effluent.
(2) Oxygen consumed on raw sewage, septic tank and contact bed effluents.
(3) Oxygen demand on septic tank and contact bed effluents.
(4) Settling solids (Imhoff cones) on raw sewage or effluents.
(5) Chlorine on raw sewage or effluent.
(6) Nitrates on septic tank and contact bed effluents.
(7) Nitrites on septic tank and contact bed effluents.
(8) Putrescibility on effluent.
(9) Bacterial count on litmus-lactose agar after 24 hours incubation at 37 C.

LABORATORY TESTS.

The following laboratory tests were made on composite samples:

(1) Total nitrogen.
(2) Free ammonia.
(3) Nitrates.
(4) Nitrites.
(5) Chlorine.
(6) Total solids.
(7) Dissolved solids.
(8) Suspended solids.
(9) Fats.

Individual tests, such as growth on gelatine, microscopical examinations, etc., were run from time to time.

LABORATORY EQUIPMENT.

The equipment of the Water and Sewage Laboratory of the Kansas State Board of Health was used during the investigation. The outfit for the portable laboratory consisted of:

(1) One 37° C. incubator.
(2) One 20° C. incubator.
(3) One three-burner gasoline hot plate.
(4) Ten shipping cases, each holding three 1-liter bottles.
(5) Ten shipping cases, each holding two 2-liter bottles; sixteen 150 cc. bottles; sixteen 250 cc. bottles.
(6) Four shipping cases, each holding 15 petri dishes, packed in a copper can with space for ice.

The apparatus purchased consisted of:

2 automatic recording water-level gauges.
300 150 cc. bottles.
300 250 cc. bottles.
6 50 cc. glass-stoppered burettes.
25 250 cc. Ehrlenmeyer flasks.
24 50 cc. Nessler tubes.
24 100 cc. Nessler tubes.
24 50 cc. casseroles.
2 1,000 cc. Imhoff cones.
450 petri dishes.
1,000 test tubes.
Graduates, beakers, measuring flasks, etc., were furnished by the Water and Sewage Laboratory.

SAMPLING PROGRAM.

Owing to lack of help, it was impossible to arrange for sampling at regular intervals throughout the twenty-four hours. Samples were taken at 7 a. m., 10 a. m., 3 p. m., and 6 p. m. A portion of each of these samples proportional to the flow at the time of sampling, as calculated from the following table, was used to form a composite sample.

Hour Sampled.	Result of test. Parts per million.	This test is representative of period below.	Hours in period.	Average flow per hour during period. Cu. ft. per sec.	Total flow for period, in gallons.	Factor.	Weighed result.
7 a. m.	90	10 p. m.– 8 a. m.	10	.2	54,000	1.04	93
10 a. m.	150	8 a. m.–11 a. m.	3	.4	32,400	.60	90
3 p. m.	350	11 a. m.– 5 p. m.	6	.5	81,000	1.56	546
6 p. m.	200	5 p. m.–10 p. m.	5	.3	40,500	.80	160

$$93 + 90 + 546 + 160 = 889$$

$$\frac{889}{4} = 222 = \text{average.}$$

GAUGINGS OF FLOW.

Gaugings of the sewage flow were made by means of a 90° triangular notch weir, continuous readings being obtained by means of a Bristol automatic recording water-level gauge, with charts arranged for seven days' flow, graduated in inches head of water. The flow was calculated by the formula—

$q = .529\ x\ 8/15 \sqrt{2g}\ H.^{5/2}$ in which
q is flow in cubic feet per second;
g is 32.2;
H is head of water in feet.

For convenience, the values were plotted on a curve with head as ordinates and flow as abscissæ. (See Figures 1 and 2.)

Figure 1 is prepared for use when the depth of sewage above the lowest point of the notch is less than 8 inches.

Figure 2 is prepared for use when the depth is above 8 inches. When the depth of sewage over a triangular weir is more than 1.5 inches a weir plate of the Cippoletti type should be used.

A drawing of the standard 90° Notch weir and the Cippoletti type weir is given in Figure 3, together with a box for use with open outlets.

Explanation of the Tests.

(1) *Oxygen dissolved.* Sanitary sewage as it comes from the homes is made up of household wastes, fecal matter, urine, etc., diluted with city water, which water is, as a rule, nearly pure and practically saturated with dissolved oxygen. As the mixture flows

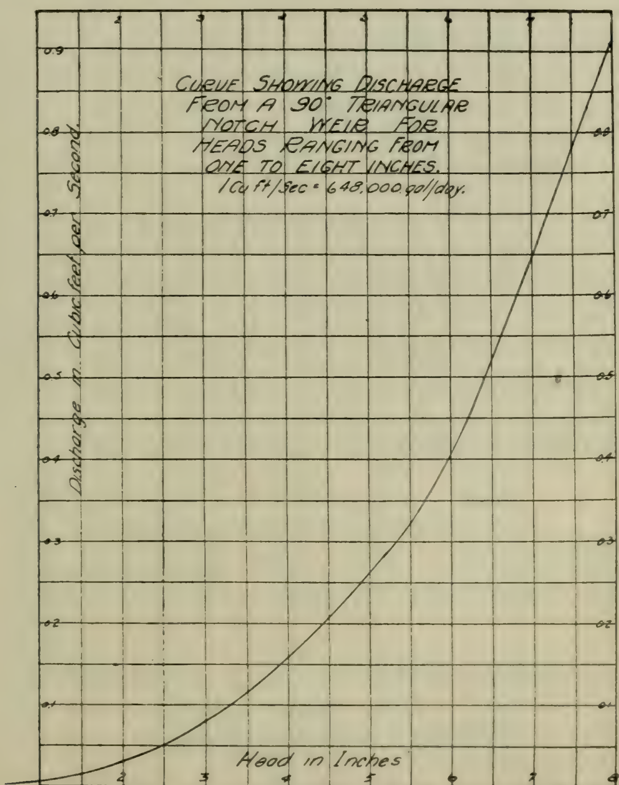


FIG. 1.

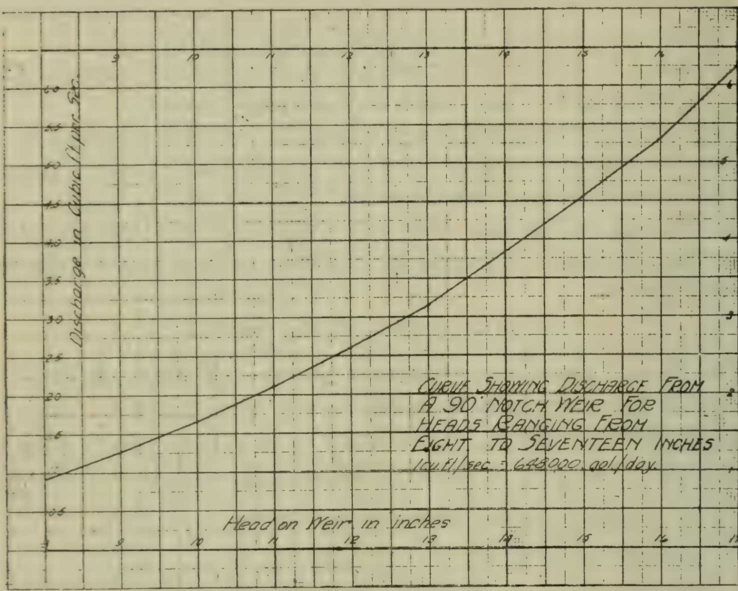


FIG. 2.

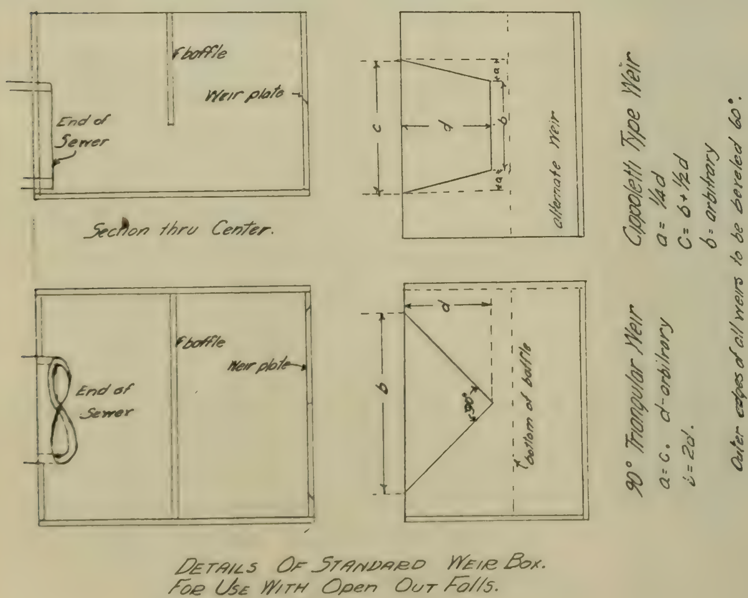


FIG. 3.

Showing weir box, for use on open-sewer outfalls, and two standard weirs.

down the sewer the organic matter begins to decompose, taking up oxygen from the diluting water as the process goes on; therefore, it may be seen that the oxygen test is an index of the freshness of the sewage. A series of these tests, when made at different intervals along a stream, gives a very accurate indication of the pollution of the stream.

Dissolved oxygen is normally absent from the effluent of septic tanks, as, when anaërobic decomposition is set up within the tank, products are formed which take up the oxygen of the inflowing sewage very rapidly. When septic action is not taking place in the tank the effluent may or may not contain oxygen, depending on the freshness of the sewage.

(2) *Relative stability.* A sewage may be called stable when the contained organic matter has taken such a form that it is incapable of undergoing offensive putrefaction. Relative stability is the ratio of the available oxygen in the sample to the amount required to render the sample stable. This test was made in accordance with the method of procedure outlined in the following chapter on chemical control of plants.

At times it was necessary to make dilutions of the sewages or effluents in aërated water. When this was done the results are given as "relative stability in a 1 to 10 dilution," etc.

(3) *Oxygen demand.* This test is made to determine the amount of oxygen required for rendering the sewage stable. The results are stated in parts per million of oxygen, and also in volumes of diluting water necessary to furnish the amount. The assumption was made that the stream water used for dilution contained on the average 8 parts per million dissolved oxygen, and that no nuisance was caused unless the initial oxygen of the stream was reduced more than 50 percent. Two methods were used to get at this value. They were:

(*a*) Rate of consumption method.

(*b*) Saltpeter method. The second method gave much the better results, and was used exclusively after the first few months of the tests.

(4) *Oxygen consumed.* This test is an index of the amount of oxygen required to oxidize the organic matter present in the sewage. Although some inorganic materials are oxidized at the same time, the test is sufficiently accurate for use in a comparative way. In this work the five-minute boiling period of digestion was used,

this being the period generally used in this country for sewage analysis.

(5) *Chlorine.* In sections of the country where the ground and surface waters contain little chlorine, the test for chlorine is a good indicator of sewage strength, and unusual amounts of chlorine in waters is a sure sign of pollution by sewage.

In Kansas, however, this is not always true, since many of our waters are heavily charged with chlorine from salt deposits or mine or oil-well drainage. The result of chlorine tests, therefore, must be considered carefully before conclusions are drawn.

(6) *Nitrogen.* Nitrogen may appear in sewage in any or all of four forms, depending on the state of oxidation. The following list is given in the order of the extent to which the oxidation process has gone.

(1) Free ammonia.
(2) Albuminoid ammonia.
(3) Nitrites.
(4) Nitrates.

For this work, free ammonia and total organic nitrogen only were determined during the first year, but nitrites and nitrates were run during the last year to determine the amount of nitrification taking place in contact filters.

(7) *Solids.* The determinations of the amount of solids in the different forms serves as an index of the character of the sewage, the amount of sludge to be expected and the leakage into the sewers. This, therefore, is important as a means of comparison of the efficiency of the different methods of purification and the operation of the different plants.

The solids in sewage may take any one of the three forms, viz:

(1) Dissolved.
(2) Suspended.
(3) Colloidal.

Any one of these forms may be composed of either mineral or organic matter. The significance of separating them is therefore easily seen. Owing to lack of time and facilities, the colloidal matter was not given attention in these tests; nevertheless, the determination is very important, especially in connection with secondary treatment, which has as its aim the mineralization of the organic matter in the sewage.

(8) *Bacterial analysis.* No attempt has been made in this work to differentiate the species of bacteria in the sewage further than

to get separate counts of the total number of colonies on lactose-litmus agar at the end of an incubation period of 24 hours at a temperature of 37° C., and a simultaneous count of the red colonies. These red colonies are generally formed by members of the colon group of intestinal bacteria, and it is the custom to assume that pathogenic bacteria may be expected where these are found. During the first year of the test the samples were plated in the field and sent, packed in ice, to Lawrence for incubation. A 37° incubator was included in the field kit the second year.

Bacterial tests for plant control are not recommended for use on tanks or contact filters, since chemical tests are much more easily made and are really better. Of course, when sand filters or disinfection plants are concerned bacterial tests are necessary.

Personnel of Staff.

The work was in joint charge of Prof. W. A. Whitaker, director of the Division of State Chemical Research, and Prof. C. A. Haskins, engineer for the State Board of Health. Prof. C. C. Young, director of the Water and Sewage Laboratory, directed the chemical and bacteriological tests. The field tests were made by Mr. F. M. Veatch. The laboratory work in Lawrence was done by Messrs. L. E. Jackson and H. P. Evans.

In the following report an attempt was made to approach the subject from the standpoint of the plant operator rather than from that of the chemist or bacteriologist. Some technical data is necessary in such a report, but this has been expressed in as simple a form as possible.

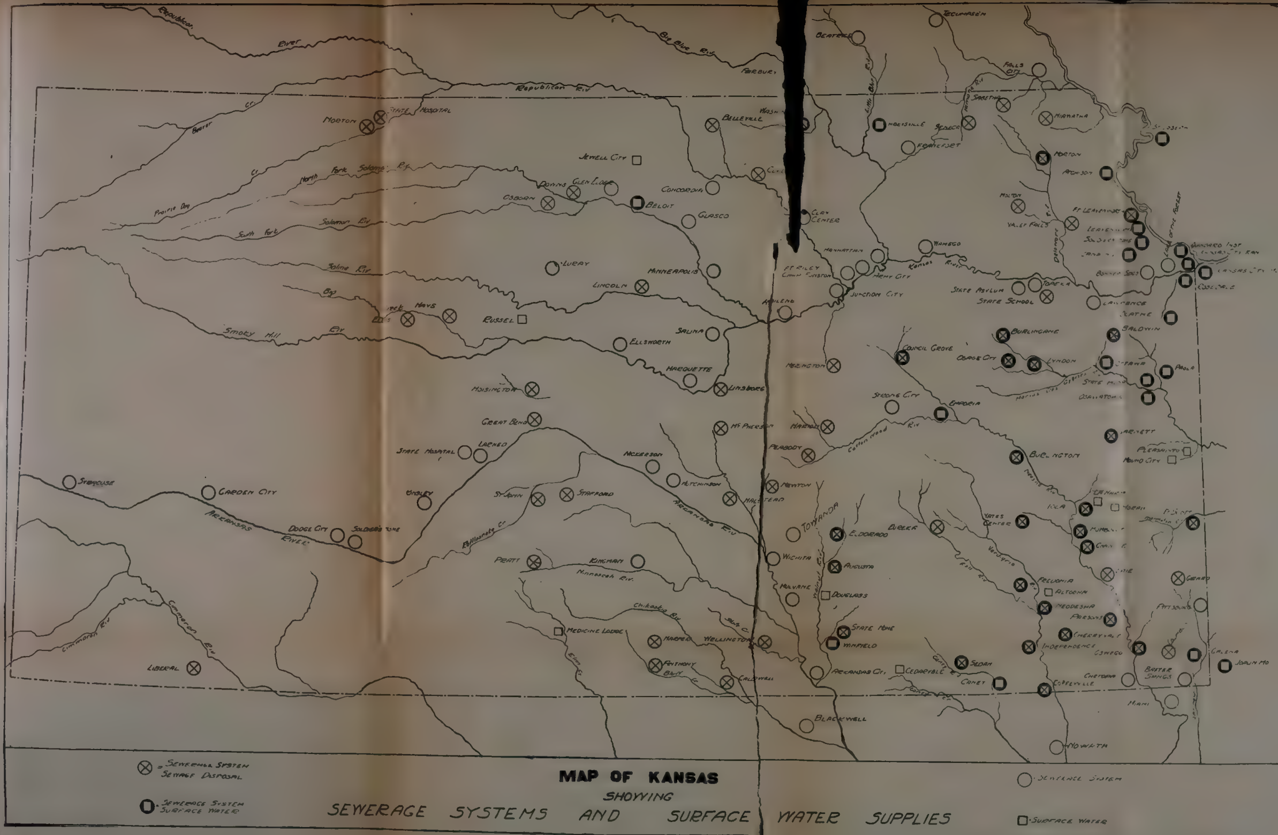
CHAPTER II.

THE SEWAGE DISPOSAL PROBLEM IN KANSAS.

By C. A. HASKINS, Engineer, State Board of Health.

THE water and sewage law of the state of Kansas, which is chapter 382, Laws of 1907, as amended by chapter 226, Laws of 1909, delegates to the State Board of Health the task of preserving the purity of "waters of the state" in the following section:

"SEC. 4. That no person, company, institution or municipality shall place or permit to be placed or discharged or permit to flow into any of the waters of the state any sewage, except as hereinafter provided. But this act shall not prevent the discharge of sewage from any public sewer system owned and maintained by a municipality or sewerage company, provided such sewer system was in operation and was discharging sewage into the waters of the state on the 20th day of March, 1907; but this exception shall not permit the discharge of sewage from any sewer system that shall have been extended subsequent to the aforesaid date, nor shall it permit the discharge of any sewage which, upon investigation by the State Board of Health, as hereinafter provided, shall be found to be polluting the waters of the state in a manner prejudicial to the health of the inhabitants thereof. For the purposes of this act, sewage is hereby defined as any substance that contains any of the waste products or excrementitious or other discharges from the bodies of human beings or animals, or chemical or other wastes from domestic, manufacturing or other forms of industry. Whenever complaint shall be made to the State Board of Health by the mayor of any city of the state, or by a county health officer, or by a local board of health, of the pollution or of the polluted conditions of any of the waters of the state situated within the county within which the said city or health officer or local board of health is located, it shall be the duty of the State Board of Health to make an investigation covering the pollution or the polluted condition concerning which complaint is made. Also, whenever the State Board of Health shall have reason to believe that any of the waters of the state are being polluted in a manner prejudicial to the health of any of the inhabitants of the state, it may upon its own motion investigate such pollution. Whenever an investigation shall be undertaken by the State Board of Health, under either of the foregoing provisions, it shall be the duty of any person, company, corporation, institution or municipality concerned in such pollution to furnish, on demand, to the State Board of Health such information as may be required relative to the amount and character of the polluting material discharged into the said waters by such person, company, corporation, institution or municipality. And if the State Board of Health shall find that any of the waters of the state have been or are being polluted in a manner prejudicial to the health of any of the inhabitants of the state, the State Board of



MAP OF KANSAS SHOWING SEWERAGE SYSTEMS AND SURFACE WATER SUPPLIES

Health shall have the authority to make an order requiring such pollution to cease within a reasonable time, or requiring such manner of treatment or of disposition of the sewage or other polluting material as may in its judgment be necessary to prevent the future pollution of such waters, or both. And it shall be the duty of the person, company, corporation, institution or municipality to whom such order is directed to fully comply with the said order of the State Board of Health. If the person, company, corporation, institution or municipality shall consider the requirements of the said order to be illegal or unjust or unreasonable, it may, within thirty days after the making of the said order, appeal therefrom to the district court of the county in which the pollution or polluted condition occurs; and the said court shall hear the said case without delay, and shall render a decision approving, setting aside or modifying the said order, or fixing the terms upon which said permit shall be granted, and stating the reasons therefor."

There are two prime reasons for maintaining the purity of streams: first: for the protection of water supplies; and second, for the prevention of nuisances, which may cause actual damage to property or inconvenience to the residents of a community. Other reasons for sewage treatment, such as the protection of bathing beaches, protection of shell-fish layings, etc., are not of great importance here.

Of the 213 public water-supply systems in Kansas at this time, 54 utilize as a source of supply, either in whole or in part, surface water from streams, lakes or ponds. Of the 54 such systems, 45 use surface water entirely; the other 9 using streams in the vicinity of the plants only as an auxiliary supply at times of an unusual drouth or at times of an excessively heavy draft, and then for only short periods of time.

The important reason for sewage treatment should be, of course, the protection of public water supplies, but since it is usually more satisfactory and feasible to purify the water supply for a city than to purify the sewage of a city, which is discharged into the same stream above, the sewage treatment is not carried to complete purification, but an attempt is made to secure a more or less harmonic balance between the treatment of water supply and sewage of two or more cities on the same stream.

It is well realized among sanitarians that any water which is collected from surface areas inhabited by human beings is unsafe for domestic use without purification, and, ordinarily, surface water, whether from areas inhabited or uninhabited, is not wholesome without treatment, on account of many foreign matters carried in suspension or solution. Therefore, the Kansas State Board of Health has adopted the policy of requiring either purification or disinfection for all domestic surface water supplies.

Most of our streams in Kansas are subject to extremely large fluctuations in flow, with a minimum flow quite frequently of zero. Since the quantity of sewage which may be emptied into a stream is governed to a large extent by the quantity of free oxygen available in the water for oxidizing its organic matter, and consequently, therefore, usually upon the quantity of water flowing; and since the quantity of sewage which may be discharged into a stream is also governed quite largely by the quantity of water available for simple dilution to hide the unsightly appearance, some treatment of sewage is practically always necessary here, if not to protect a public water supply, to prevent a nuisance. The Missouri, Arkansas and Kansas rivers are the only streams in Kansas into which raw sewage may be discharged at the present time. Usually precautions are taken to find a very isolated spot for the emptying of sewage into these streams. Neither the Kansas nor the Arkansas river is used as a source of public water supply; and while the Missouri is used alike as a source of public water supply and as a means of sewage disposal by practically all cities along its banks, it is believed that conditions of minimum flow and other factors influencing self-purification are such as to not warrant the enforcing of treatment for sewage emptying into it.

On the other hand, the Neosho, Verdigris, Walnut and other rivers are used extensively for public water supplies, and cities discharging sewage into those streams are required to treat their wastes by some method or another, ranging from the simple removal of part of the suspended solids by septic-tank treatment, the removal of solids and partial oxidation of organic matter by septic tanks, Imhoff tanks and filters of sand, contact or trickling type, to complete disinfection by chlorine gas. The accompanying illustration shows the cities of the state using surface water supplies, with the streams which are utilized; and also those cities of the state with sewer systems, and the streams into which sewage is discharged, with the method of treatment, if any.

At the present time the energies of the Division of Water and Sewage of the State Board of Health are being directed intensively to the proper operation of water purification and sewage disposal plants in order to secure the best results possible with the existing equipment.

The map on the preceding page shows the relative location of sewage disposal plants and surface water supplies.

LIST OF SEWERAGE SYSTEMS IN KANSAS, WITH RECEIVING STREAMS AND METHODS OF DISPOSAL.

CITY.	Population, 1910.	Sewage discharges into	Treatment or disposal.*
Abilene	4,118	Smoke Hill river	Dilution.
Anthony	2,669	Spring creek	Imhoff tank and contact beds.
Arkansas City	1,508	Arkansas river	Dilution.
Atchison	16,429	Missouri river	Dilution.
Augusta	1,235	Walnut river	Imhoff tank and contact beds.
Baldwin	1,386	Dry runs leading to Marias des Cygnes river	Septic tanks and contact beds.
Baxter Springs	1,598	Spring river	Dilution.
Beloit	3,082	Solomon river	Dilution.
Bonner Springs	1,462	Kansas river	Dilution.
Burlingame	1,442	Switzler creek	Imhoff tank and contact beds.
Burlington	2,180	Neosho river	Septic tank.
Caldwell	2,205	Fall creek	Septic tank.
Caney	5,061	Cana creek	Dilution.
Chanute	9,272	Neosho river	Septic tank.
Cherryvale	5,572	Drum creek	Septic tank and contact beds.
Chetopa	1,548	Neosho river	Dilution.
Clay Center	3,438	Republican river	Dilution.
Clyde	1,057	Republican river	Dilution.
Coffeyville	12,687	Two outfalls on Verdigris river and one on Onion creek	Septic tanks; 3 plants.
Columbus	3,064	Brush creek	Septic tank and contact beds; 2 plants.
Concordia	4,415	Republican river	Dilution.
Council Grove	2,545	Neosho river	Imhoff tank and contact beds.
Dodge City	3,214	Arkansas river	Dilution.
Downs	1,427	North fork of Solomon river	Septic tank.
El Dorado	3,129	Walnut river	Septic tank disinfection.
Ellis	1,404	Big Creek	Septic tank and contact beds.
Ellsworth	2,041	Smoky Hill river	Dilution.
Emporia	9,058	Cottonwood river	Dilution.
Erie	1,300	Neosho river	Septic tank.
Eureka	2,333	Fall river	Septic tank.
Fort Scott	10,463	Marmaton river	Septic tank.
Frankfort	1,426	Black Vermillion river	Dilution.
Fredonia	3,040	Salt creek	Septic tank.
Galena	6,096	Short creek	Dilution.
Garden City	3,171	Arkansas river	Dilution.
Garnett	2,334	Dry ravines leading to Pottawatomie creek	Two plants; septic tanks and contact beds.
Girard	2,446	Cow creek	Septic tank and contact beds.
Great Bend	5,500	Walnut creek	Septic tank.
Halstead	1,004	Little Arkansas river	Septic tank and contact beds.
Harper	1,658	Bluff creek	Septic tank and contact beds.
Hays City	1,961	Big creek	Septic tank.
Herington	3,273	Lime creek	Septic tank.
Hiawatha	2,974	Wolf creek	Imhoff tank; sand filter.
Hoisington	1,974	Cheyenne bottoms	Septic tank.
Holton	2,842	Elk creek	Septic tank and contact beds.
Horotn	3,600	Cedar creek	Septic tank and contact beds.
Humboldt	2,548	Neosho river	Septic tank.
Hutchinson	16,364	Arkansas river	Mechanical screens, three-eighths slats.
Independence	10,480	One-third Rock creek, two-thirds Verdigris river	One-third septic tank and contact beds, two-thirds dilution.
Iola	9,032	Elm creek	Septic tank.
Junction City	5,598	Smoky Hill river	Dilution.
Kansas City	85,697	Kansas river	Dilution.
Kingman	2,570	Ninnescah river	Dilution.
Kinsley	1,547	Arkansas river	Dilution.
Larned	2,911	Arkansas river	Dilution.
Lawrence	12,374	Kansas river	Dilution.
Leavenworth	19,363	Missouri river	Dilution.
Liberal	1,716	Dry lake	Septic tank and sand filters.
Lincoln	1,508	Saline river	Septic tank.
Lindsborg	1,939	Smoky Hill river	Dilution.
Lyndon	763	Salt creek	Septic tank and contact beds.
McPherson	3,546	Turkey creek	Septic tank, Imhoff tank and sand filter.
Manhattan	7,722	Blue river	Dilution.
Marion	1,841	Cottonwood river	Septic tank.
Marysville	2,260	Blue river	Dilution.
Minneapolis	1,895	Solomon river	Dilution.
Mulvane	1,084	Arkansas river	Dilution.

LIST OF SEWAGE SYSTEMS IN KANSAS—CONCLUDED.

City.	Population, 1910.	Sewage discharges into	Treatment or disposal.*
Neodesha	2,872	Verdigris river	Imhoff tank, sprinkling filter.
Newton	7,862	Sand creek	Septic tank.
Nickerson	1,195	Arkansas river	Dilution.
Norton	1,787	Prairie Dog creek	——
Olathe	3,272	Mill creek (dry)	Dilution.
Osage City	2,432	Salt creek	Septic tank and contact beds.
Osawatomie	4,046	Pottawatomie creek	Dilution.
Osborn	1,566	Solomon river	Septic tank.
Oswego	2,317	One-third Dry creek, two-thirds Neosho river	One-third septic tank, and contact beds; two-thirds dilution.
Ottawa	7,650	Marias Des Cygnes river	Dilution.
Paola	3,207	Bull creek	Dilution.
Parsons	12,463	Little Labette creek	Two septic tanks.
Peabody	1,416	Doyle creek	Septic tank.
Pittsburg	14,765	Cow creek	Dilution.
Pratt	3,302	Ninnescah river	Septic tank.
Rosedale	5,960	Turkey creek	Dilution.
Sabetha	1,768	Cedar creek	Two plants; septic tank and contact beds.
St. John	1,785	Rattle Snake creek	Septic tank.
Salina	9,688	Smoky Hill river	Dilution.
Sedan	1,211	Cana creek	Dilution.
Seneca	1,806	Nemaha river	Septic tank and contact beds.
Stafford	1,927	Ninnescah river	Septic tank and contact beds.
Syracuse	1,000	Arkansas river	Dilution.
Topeka	43,684	Kansas river	Dilution.
Valley Falls	1,129	Delaware river	Imhoff tank.
Wamego	1,714	Kansas river	Dilution.
Washington	1,547	Mill creek	Septic tank.
Wellington	7,034	State creek	Two plants; septic tanks.
Wichita	32,450	Arkansas river	Dilution.
Winfield	6,700	Walnut river	Dilution.
Yates Center	2,024	Ravine to Owl creek	Septic tank and contact beds.

*See folded map on inside back cover.

CHAPTER III.

A REVIEW OF THE SEWAGE DISPOSAL PRACTICE IN AMERICA

THIS chapter is devoted to a short description of the methods in general use for the disposal of sewage. No attempt is made to explain the intricate details of the many chemical, physical and biological processes which take place in the different types of disposal plants, since the object of this bulletin is to place in the hands of every plant operator data which may be used in the care of the plant, rather than to furnish a complete scientific description of the processes.

Not until of late years has the problem of sewage disposal been attacked along scientific lines, although sewage disposal has been a factor in civic life ever since the population of the earth began to congregate in cities. It is admitted by experts that the problem is yet in solution and that the best methods so far devised are not as efficient under all conditions as is desired.

Rapid progress is being made in the number of works constructed and in the methods of disposal. Based on the 1910 census, which gives the population of the United States as 91,600,000, the following statistics have been compiled by Mr. George M. Wisener, chief engineer of the Sanitary District of Chicago:

38 percent, or 34,700,000, live in places provided with sewerage systems.
11 percent, or 3,900,000 (of the above) were tributary to treatment works.
89 percent, or the remaining population has its sewage discharged into water untreated.

The type of treatment employed has been constantly changing and has advanced from the old-time sewage farms, which at best could handle only some 10,000 gallons of sewage per acre per day to the modern trickling filter, which may treat 2,000,000 gallons per acre per day. At the present time experiments on the activated sludge method seem to show that this rate may still be increased.

Definition of Terms.

A few definitions of terms and a few words in reference to the composition of sewage are desirable here.

Sewage is known as "fresh" when the solid matters have undergone little or no decomposition and the carrying liquid is clear, and contains dissolved oxygen.

Sewage is called "septic" when the solid matters are in an advanced state of decomposition. The carrying liquid does not contain dissolved oxygen and has a disagreeable cesspool odor.

"Sanitary sewage" is that composed of domestic waste only.

"Combined sewage" is that from systems which carry domestic waste, trade waste, storm water, street washings, etc.

Bacterial action which takes place in the presence of air is called "*aërobic,*" and that which takes place in the absence of air, "*anaërobic.*"

"Sewage disposal" implies the elimination of the sewage with as little nuisance as possible, and must not be confused with "sewage purification," which implies the production of pure water from the sewage.

Composition of Sewage.

The average Kansas sewage may be considered composed of 1 part of solid matter to 700 parts of water. With this solid matter and its removal, or change of form, sewage treatment has to deal. The composition of the solid matter varies greatly with local conditions, but the average sanitary sewage of Kansas is composed, roughly, of one-third mineral matter and two-thirds organic matter. Solids in sewage may be classified as to their physical and chemical properties as follows:

- (1) Physical.
  - (*a*) Dissolved.
  - (*b*) Suspended but capable of settling.
  - (*c*) Colloidal, *i. e.*, in a state of semisolution or extremely fine, neither dissolved nor capable of settling without special treatment.
- (2) Chemical.
  - (*a*) Mineral: inorganic salts.
  - (*b*) Organic.
    - Carbonaceous.
    - Nitrogenous.

The mineral matter is composed of grit and dissolved inorganic salts, and, as a rule, does not materially affect the operation of disposal, since the grit settles out readily and the inorganic salts generally remain in solution and may be disregarded. Certain trade wastes may carry germicides or coagulants which, when encountered, call for some special treatment. This treatment, it is generally found, can be more economically undertaken at the source of the waste than after it has been diluted with other sewage.

When a city is sewered on the combined plan—that is, when storm water and sanitary sewage are carried in the same conduits—the proportion of mineral matter will be greatly increased owing to street washings, etc. The organic solid matter, then, is really what we must consider in the treatment of sewage. Approximately five-eighths of the organic matter is composed of carbon, hydrogen and oxygen, consisting of carbohydrates, fats, and other similar substances, which for convenience will be called carbonaceous organic matter. The remaining three-eighths consists of compounds of nitrogen, sulphur, and phosphorus, and will be known as nitrogenous organic matter. A distinction is made between these classes when decomposition is considered, since the products of decomposition are different. Fermentation is the term used to indicate the decomposition of carbonaceous matter, while the term putrefaction indicated decomposition of nitrogenous matter.

Carbonaceous matter is, as a rule, more stable and more easily separated from the sewage than is the nitrogenous matter. As a result, the problem simplifies itself to the removal of the nitrogenous organic matter or changing it to a stable form. When this has been done the disposal of carbonaceous material has usually been accomplished.

Sewage Disposal.

Sewage disposal is resorted to for several reasons, viz:

First. To prevent the receiving body of water from becoming offensive to the eye because of floating matter.

Second. To prevent the fouling of such waters.

Third. To keep the germs of disease from the body of water, and hence to protect communities which depend upon it for a water supply.

The problem may be attacked in two fundamentally different ways, viz.:

(1) By the complete removal of the organic matter from the sewage.
(2) By its change of form from unstable compounds into those more stable and finally into mineral compounds that are harmless.

The methods which have been tried extensively or are in general use at the present time are:

(1) Dilution.
(2) Screening.
(3) Sedimentation.
  (*a*) Plain settling, either rapid as in grit chambers; or slow, as in settling basins or tanks.

(*b*) With aid of chemicals.
(*c*) With septic action.
(*d*) With aëration, with or without aid of coagulants.
(4) Treatment on contact beds, sprinkling or trickling filters.
(5) Application to land.
(*a*) Intermittent sand filtration.
(*b*) Sewage farming or broad irrigation.
(6) Disinfection.

A plant for sewage disposal may involve any one of these, but as a rule it is made up of a combination of two or more of the above-named processes, and the treatment of the sewage is carried forward a step at a time.

Disposal by Dilution.

Disposal by dilution consists in the utilization of the oxidizing power of natural water for the purification of sewage. Upon dilution the following actions take place to a greater or lesser degree.

(1) Disinfection by sunlight.
(2) Use of floating matter as food for birds and animals.
(3) Use of suspended matter as food for fish.
(4) Use of dissolved and suspended organic matter by plant life.
(5) Oxidation by the oxygen dissolved in the water and in the air.

As a result of these actions the unstable matter discharged into the stream is changed into a more stable form, and if the process is carried to completion the resulting substances are carbon dioxide, nitrates and water.

Temperature is an important factor in the determination of the amount of sewage that may be added safely to a given amount of water, since bacterial action is more marked at relatively high temperatures, and since the amount of oxygen that may be dissolved in water varies indirectly with temperature. These facts make it possible to add approximately twice as much sewage of a given strength to a given amount of water in winter than in summer.

Figure 4 shows the effect of temperature on the dissolved oxygen content as well as the effect of large volumes of diluting water.

In America it is generally considered that a flow of 4.5 cubic feet per second is sufficient for the dilution of the sewage of 1,000 persons. This is equal to a dilution of one part of sewage in thirty

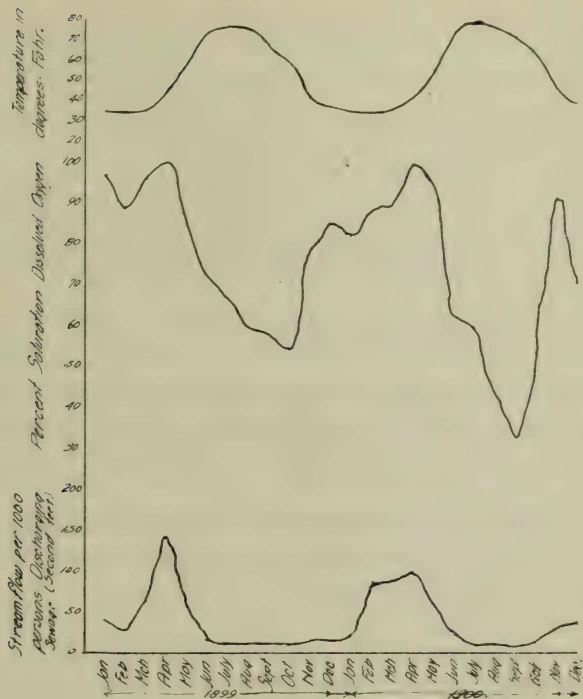


Diagram Showing Seasonal Conditions in Merrimac River at Lawrence Mass (from Fuller)

FIG. 4.

From "Sewage Disposal," Geo. W. Fuller, 1913.

parts of water. Kansas sewage, however, is, as a rule, stronger than the American average, and a dilution of one in fifty is often necessary.

Screening.

Screening, though classed as a disposal method, is generally employed in connection with other methods as a preliminary treatment.

Screens are classified as coarse, medium and fine, according to the size of the particles that they will remove from the sewage.

Coarse screens remove particles above two inches in diameter.

Medium screens remove particles one-fourth inch to two inches in diameter.

Fine screens are designed to collect very small suspended matter and have open spaces one-fourth inch or less. Much attention has been given in late years to the work done by fine screens, and

in some cases it has been reported that their operation compares favorably with that of settling basins. It is possible, therefore, by fine screening, to materially increase the efficiency of subsequent treatment or to increase the amount of sewage that may be added safely to a given amount of water.

There are some objections to the process:

(1) The disposal of screenings, which are sometimes very offensive.
(2) The increase of the amount of solid matter in colloidal form, due to the impact and attrition of the sewage as it strikes the screen.
(3) The necessity of mechanical devices for cleaning. The small apertures clog rapidly if not given constant attention.

There are no installations of fine screens in Kansas, but medium sized screens are used in several cases to protect pumps and to remove the coarser matters from sewage before it is treated in tanks.

The disposal of the screenings is a point which should receive attention. In some of the larger disposal plants where the amount of screenings is large, methods such as incineration or reduction are sometimes employed, and, at times, it is attempted to recover some of the grease, etc. The small amount of screenings encountered in a plant of the size found in Kansas does not warrant any method of disposal other than by burying or dumping in some isolated place.

Disposal by Sedimentation.

Sewage disposal by sedimentation may be carried out either by rapid or slow settling.

Rapid sedimentation, as the name implies, refers to the practice of allowing the sewage to pass through suitable chambers with a velocity high enough to transport the lighter suspended matters, but slow enough to allow the heavier matters to be deposited. The devices used for this purpose are known as grit chambers or detritus tanks, and are very useful in preventing sand and grit from entering the different parts of the plant and forming heavy sludge. In the case of plants which treat combined sewage these are very important, but since most of our Kansas disposal plants are connected to separate sewers, grit chambers are not generally necessary, and in fact would really be a detriment, since the sediment which they would collect would be very offensive.

Slow settling is applied in several ways, classified according to the method of application:

(1) Plain settling in tanks.
(2) Settling with septic action in single-story tanks.
(3) Settling with sludge digestion in two-story tanks.
(4) Settling with aid of chemicals.
(5) Settling with plain aëration.
(6) Settling with coagulants.
(7) Settling with aëration and the addition of thoroughly nitrified sludge.

By "plain settling" we mean merely the physical separation of the solids from the liquid.

This is accomplished either by allowing sewage to remain quiet in a tank for a period sufficiently long to allow the greater part of the solid matter to settle; or by allowing sewage to flow through a tank so designed that its velocity will be reduced to a point at which the greater part of the solids will be deposited.

Little difference is shown in the results of the two methods, but on account of ease of operation the continuous flow method is in general use.

Experiments made under widely varying conditions show that while it is not possible to remove all the suspended solids, practically all that may be removed are deposited in well-designed tanks in five hours; and further, that all but from 2 to 5 percent of this amount is deposited in the first two hours. It is therefore customary to design settling tanks with a capacity of two to five hours flow of sewage.

Settling tanks may be designed for horizontal, vertical or radial flow, the depth varying with structural possibilities or the preference of the designer. Deep tanks give a better grade of sludge, but are more expensive than shallow basins.

Adequate provisions must be made for cleaning settling tanks frequently, so as to prevent the starting of septic action with its resulting fouling of the effluent.

Plain settling, when carefully practiced, gives an effluent with two-thirds to three-fourths of the original suspended solids removed, with very little increase in the amount of solids in colloidal state; and in good condition for subsequent treatment by dilution or on contact beds or filters.

SEPTIC ACTION.

When the detention period is made sufficiently long, septic action takes place in a settling tank. Such a basin is known as a septic tank. The physical action of sedimentation still operates, but it is accompanied by decomposition of the organic matter due to the action of anaërobic bacteria. Loss of dissolved oxygen is the fiirst indication of septic action, but it is very quickly followed by the formation of bubbles and scum on the surface and the evolution of offensive odors.

Removal of solids by the septic process is essentially the same as that effected by plain settling, but the character of the effluent is very different. Much of the suspended matter is changed into a collodial state. The effluent is devoid of dissolved oxygen, has a disagreeable "cesspool" odor, and is extremely unstable.

It has been claimed by some investigators that the breaking down of the complex organic matters by septic action makes their subsequent oxidation more easily accomplished. Recent work has shown that the opposite is true, and effluents from septic tanks commonly require more water for their dilution than does the sewage which was treated by plain settling. On the other hand, owing to compacting and bacterial action in the septic tank, the amount of sludge is materially diminished. The amount of this shrinking is variable, but as a rule is not more than one-third.

The detention period necessary to produce septic action is generally from eight to twenty-four hours, varying with the temperature and character of the sewage. Stale, strong sewages at summer temperature become septic very quickly.

TWO-STAGE TANKS.

Sludge from septic tanks may be air-dried with much less offensiveness than can sludge obtained from settling tanks. The desirability of obtaining sludge of septic-tank quality, without rendering the sewage septic, has caused the development of the two-stage tank. These tanks have two compartments, one above the other. The upper compartment is a settling basin with capacity for from thirty minutes to two hours flow, and is connected to the lower compartment by a longitudinal slot. The lower compartment is a sludge digestion chamber and has sufficient capacity for storing sludge for several months.

Several types of these tanks have been developed, but the more important are those of Travis and Imhoff. In the Travis tank,

however, a small portion of the sewage is allowed to run through the digestion chambers, while in the Imhoff tank the flowing sewage is, as far as possible, isolated from the digesting sludge.

CHEMICAL PRECIPITATION.

Chemicals are sometimes added to sewage, and, by coagulation, cause more complete precipitation of the suspended and colloidal matter. Many chemicals have been tried for this purpose, but the following are the most generally in use, on account of their efficiency and low cost:

(1) Lime.
(2) Sulphate of aluminum, commonly known as "alum."
(3) Ferrous sulphate, commonly known as "copperas."
(4) Ferric sulphate.
(5) Alumino-ferric.

The use of these chemicals, with the exception of lime, requires that the sewage be in an alkaline condition in the form of carbonates or bicarbonates, so that the resulting compounds may be iron or aluminum carbonates. These are, by hydrolysis, immediately changed into the respective hydroxides, which form the coagulating precipitates. The process from this point consists merely in the physical action of settling. Lime is used, as a rule, only when sewage contains free acid, which must be neutralized before the coagulant may become effective.

Tanks for chemical precipitation are generally designed for a detention period of six to eight hours.

The chemical dose varies so greatly with sewages of different composition that analysis of the sewage is necessary before treatment. From 400 to 600 pounds of lime, or 50 to 75 pounds of alum, or copperas, are required, on an average, per million gallons treated. More sludge is produced by this method than by any other, and its disposal must be taken into consideration.

The amount of purification possible by this method depends largely upon the amount of chemical used. It is possible, by use of sufficient chemicals, to render sewage clear, stable and free from color, and remove 98 to 99 percent of the bacteria. This is practical, however, only in exceptional cases, owing to cost of chemicals.

COLLOIDAL MATTER.

The colloidal matter in sewage has always caused trouble to the operator, and until late years the only methods for its removal were chemical precipitation or filtration.

ACTIVATED SLUDGE.

Aëration has been used for years to improve the quality of settling-tank effluents, especially when these have a tendency to become septic, but it was not until 1910 that the activated sludge treatment was begun. It was noticed that final sedimentation could be aided, and a great reduction of putrescibility effected, by forcing air through the sewage in tanks before settling, and it was noted also that nitrification proceeded while the aërated sewage was settling.

The underlying principles of this method comprises the oxidizing power of atmospheric oxygen and the nitrifying power of aërobic bacteria. That bacteria play an important part is proved by the fact that the process is much more efficient at high than at low temperatures.

Early installations for activated sludge treatment consisted of tanks with series of roofing slate placed vertically with clear spaces of about one inch. Air was applied through perforated pipes, and after forcing the air through the sewage for some time a brown gelatinous coating formed on the plates and seemed to exert a coagulating influence on the suspended matter of the sewage. From time to time this coating would slip to the bottom of the tank as a sludge.

Recent practice has been to aërate sewage in open tanks without the use of plates. Air pipes have been replaced by filter plates, which distribute the air more evenly through the liquid and the settling is obtained in a separate basin.

AËRATION PERIOD ACTIVATED SLUDGE.

Shorter periods of aëration have been obtained by pumping a small amount of sludge from the final settling basin back into the aërating tank, thus inoculating the sewage with nitrifying bacteria.

The sludge as it passes into the settling basin from the aëration tanks resembles the floc obtained by chemical coagulation. The colloidal turbidity is reduced greatly by coagulation. The sludge obtained often contains as high as 6 percent available nitrogen, and therefore is especially adapted to use in fertilizers.

Owing to the machinery and attention necessary, the adaptability of this form of treatment to small plants is problematical, and the degree of efficiency that may be obtained by remotely operated electric machinery is not known.

Contact Bed Treatment.

The contact bed was the first departure from tank treatment and the first step toward the removal of colloidal matter. It consisted of a water-tight, uncovered tank filled with stone, coke, slag or some other inert material, generally broken to uniform sizes ranging from one-half inch to four inches in diameter. Suitable valves, siphons, etc., were provided to allow for filling the tank for holding the sewage in contact with the ballast, and finally for draining.

The purification of the sewage is accomplished by the combined forces of—

(1) Plain settling or straining.
(2) Surface attraction.
(3) Action of bacteria on organic matter.

Thus the same set of physical, chemical and bacterial actions are encountered here as in disposal by dilution.

The cycle of operation of contact beds is very important and consists of four periods, namely:

(1) Time of filling.
(2) Time of contact.
(3) Time of emptying.
(4) Time of rest.

It is now thought that the greater part of the nitrification takes place when the sewage is out of the bed and the deposit on the ballast has free access to the air. The practice is to allow a period of rest at least three times as long as the combined periods of filling, contact, and emptying. The periods of filling and emptying are generally fixed by the size of the inlet and outlet pipes. The period of contact varies from forty-five minutes to four hours. The trend of practice is, however, toward the shorter period.

CAPACITY.

It is customary to allow one acre of beds, four feet deep, to each 600,000 gallons of sewage. This dose is capable of being changed greatly by operation, and many well-operated plants are treating sewage at rates greatly in excess of this amount, while others, which are not so well looked after, are not able to treat successfully one-half this amount.

The bacterial actions in the contact bed are essentially aërobic, in contrast to the anaërobic action of the septic tank. Before extensive nitrification can take place it is necessary for the aërobic

bacteria, which cause this action, to outnumber the anaërobes. The bacteria in septic sewage are largely anaërobes, while those of fresh settled sewage are, at least, partially aërobes; hence, the efficiency of the contact bed is best with fresh-settled sewage and poorest with oversepticized sewage. Under good conditions, a removal of about 80 percent of bacteria, 90 percent of suspended and colloidal matter, and 65 to 70 percent of organic matter may be expected.

TRICKLING FILTERS.

The need of plants of greater capacity per unit area has caused the development of the trickling or sprinkling filter. This method differs from the contact method only in the manner of applying the sewage and in the construction of the units.

The sewage is applied to the bed in the form of a fine spray and the nitrifying and settling actions take place as it slowly trickles over the ballast toward the underdrains. Trickling filters are commonly built six to eight feet deep and are designed to treat from one and one-half to two million gallons of sewage per acre per day. Owing to the presence of air which is at all times in the body of the ballast, and owing, also, to the aërating effect of the spray, the nitrifying action is as a rule more complete than in the contact bed, and the effluent more stable.

Under good conditions and efficient operation it is possible to remove by this method from 75 to 80 percent of the bacteria and from 85 to 90 percent of the organic matter.

Trickling filters are not generally adopted for use in small installations, since they are supposed to require more care than do contact beds. The probabilities are that they do not require much more care than the contact bed should receive, but they require more than the ordinary contact bed usually gets. In addition to this, the trickling filter requires the greater head for operation. In the contact bed it is only necessary to provide a head equal to the depth of the bed, while in the sprinkling filter there must be sufficent head to bring about a spraying action. This requires from four to six feet more than the thickness of the bed.

Application to Land.

The methods discussed thus far have had as their aim the disposal rather than the purification of sewage, and the problem has been considered solved when nuisances were avoided. If a stream of sufficient capacity for dilution is lacking, or a necessity exists

for rendering the sewage practically free from bacteria, land treatment may be adopted. Land treatment may be applied in three ways:

(1) Intermittent sand filtration.
(2) Broad irrigation.
(3) Sewage farming.

SAND FILTRATION.

Intermittent sand filtration is the application of sewage in regular doses to sand beds. The purification which results from this treatment is due to the same set of forces which operate in the contact bed or trickling filter, but these forces are greatly magnified because of the decreased size of the particles which form the bed. The straining action is carried to a greater extent, and the increased surface presented to the sewage offers far better chance for removal of colloidal matters by surface attraction than does the relatively large ballast which forms the body of the contact bed. With sufficient ventilation to insure active bacterial growths of the proper kind, the small interstices between the sand grains are very favorable to the production of a highly mineralized effluent.

Sand filters are usually constructed in units of from one-fourth to one acre in area, the size depending upon local conditions.

The rate of dosing depends upon several factors, viz.:

(1) Character of sewage treated.
(2) Character of beds as to size of grains, depth, drainage, etc.
(3) Condition of beds.

When raw sewage is treated the capacity of an intermittent sand filter is limited to about 50,000 gallons per acre per day, but by the application of good tank effluent or well-screened sewage, this amount may be increased to 100,000 gallons or more. This refers to well-constructed, well-drained beds composed of sand of a low uniformity coefficient. With poorer grades of sand, or with natural beds, the rate must be decreased often.

The successful operation of a sand filter depends upon the presence of air in the interstices of the sand at all times, and therefore it is necessary to apply the sewage to the beds in doses, and to allow a period of rest between doses, during which the bed may drain thoroughly. The length of this period depends upon operating conditions. Under favorable conditions of design and opera-

tion, a reduction of from 95 to 99 percent of the bacteria may be expected as well as a practically complete removal of the suspended and colloidal solid matter.

BROAD IRRIGATION.

The distinction between sewage farming and broad irrigation is not clearly marked, but the term "sewage farming" is generally used to designate the practice of irrigating crops with sewage with the expectation of a profit, whereas "broad irrigation" indicates that cropping has been made a secondary consideration or has been abandoned altogether.

Treatment on land with the growing of crops as a side issue is probably the oldest known method of sewage disposal, and there is evidence that the city of Athens made such use of parts of the surrounding country. Sewage farming for profit has practically been abandoned in this country, owing to the difficulties in adjustment of crop rotation to sewage flow and to the immense first cost of the necessary land and equipment.

The value of sewage as a fertilizer is also vastly overestimated, owing to the extreme dilution of the fertilizing materials and to the fact that a great deal of it is in a form not readily available to plant life. The value of sewage to crops is to be measured more in terms of irrigating water than in terms of fertilizing value. Ten thousand gallons of sewage per acre per day is a maximum figure for good soil, but if cropping for profit is to be practiced this figure would be too large, as there would be times when the sewage could not be applied to crops without damage, and other land would have to be provided for treatment.

Sterilization.

Sometimes it becomes necessary in the prevention of the spread of disease, or in the protection of some neighboring water supply, bathing beach or shell-fish bed, to sterilize sewage by the use of a disinfectant, and although this is not a complete method of disposal, it is often the most expedient. The use of sterilizing agents is also very advantageously employed in the treatment of sewage during shutdowns in the disposal plants or during epidemics, etc.

The methods in use, or proposed, for the sterilization of sewage are:

(1) Heat.
(2) Electricity.
(3) Ozone.
(4) Chemicals.

HEAT.

The sterlization of sewage by steam, with the production of ammonia as a by-product, has been proposed, but sufficient practical experience has not been recorded to warrant a statement as to whether it can be economically practiced. High prices for fuel, odors from the plant, etc., probably would preclude the construction of such a plant in most cases.

ELECTRICITY.

Several plants have been built which use an electric current to form, by electrolysis, some chemical compound which has germicidal or coagulating properties. The same results may be obtained by the addition of equal amounts of the chemical in the ordinary manner, and unless cheap power is available the addition of the chemical in the ordinary manner usually would be more economical.

OZONE.

Ozone has been successfully employed for the sterilization of water, but whether it can be produced cheaply enough to compete with other chemicals in sewage work, or whether it is powerful enough to penetrate the relatively large particles of organic matter in sewage, has not yet been shown.

CHEMICALS.

Many chemicals have been used, but the ones which have given the most promising results are:

(1) Compounds having available (free) chlorine.
(2) Lime.
(3) Acids.
(4) Copper salts.
(5) Benzoate of soda.
(6) Amines.
(7) Permanganates.

Those containing available chlorine, such as bleaching powder and gaseous chlorine, are generally the most adaptable and economical. Experiments show that the efficiency of the two as disinfectants is about equal when figures are based on available chlorine, so the choice in their use rests on the cost and convenience. Bleaching powder is cheaper per pound available chlorine, but, on the other hand, requires more labor for its use.

The amount of chlorine to be fed depends upon the degree of purification necessary and upon the condition of the sewage to be

QUANTITIES OF PRINCIPAL CONSTITUENTS IN GRAMS PER CAPITA DAILY

SEWAGE OF SMALL RURAL COMMUNITIES IN KANSAS CONTAINING LITTLE TRADE WASTE COMPARED WITH SIMILAR COMMUNITIES IN MASSACHUSETTS

			Burlingame Kans.	Osage City Kans.	Newton Kans.	Winfield Kans.*	Independence Kans.	Cherryvale Kans.	Girard Kans.	Andover Mass.	Stockbridge Mass.	Leicester Mass.	Average Kans.	Average Mass.
Inhabitants contributing sewage			305 -	875	5865	606	1310	1375	1000	3600	800	500		
Total dry weather flow			149000	28000	148515	55000	279200	219175	84150	125000	75000	30000		
Flow per person connected with sewer U.S.G.			49	32	25	92	213	159	84	35	94	60	93	63
Grams per capita daily	Total solids	Total	264	91	108	372	850	628	512	62	84	96	375	89
		Fixed	105	21	35	232	160	162	87	31	53	46	114	45
		Volatile	159	70	73	140	490	466	428	32	31	50	261	44
	Suspended solids	Total	71	8	21	149	50	184	61	14	14	32	77	23
		Fixed	37	4	12	111	30	47	33	2	3	5	39	4
		Volatile	34	4	9	38	20	137	28	12	11	27	38	19
	Dissolved solids	Total	194	84	88	251	600	440	450	48	70	64	301	67
		Fixed	69	16	24	82	150	330	54	27	50	41	103	42
		Volatile	125	68	64	169	450	110	396	21	20	23	197	25
	Nitrogen	Total	15	7	2.5	16	24	11	9	5.3	3.5	5	12	5.7
		Free NH_3	14	2	2.5	3	14	7	5.	.7	.6	.9	7	.91
	Oxygen consumed in 5 min.		80	54	47	443	145	124	123	6.5	5.4	11.5	145	Forley '18 9.14
	Chlorine		16	9	10	35	64	52	110	9.0	4.6	12	42	10.92

*INSTITUTIONAL SEWAGE

FIG. 5. Data for 1914.

treated. For screened sewage, three parts per million will cause a reduction of from 90 to 95 percent of the bacteria, but to insure complete removal 12 to 15 parts per million must be added. Septic sewage requires about the same amount as raw sewage, while three parts per million is probably the maximum amount required for the complete sterilization of good trickling filter effluent.

Little need be said of the other chemicals, since they are expensive in comparison with chlorine compounds, and therefore their use could be recommended at the present time only under unusual circumstances.

Sludge.

Sludge disposal is a very important branch of sewage disposal. The amount of sludge to be handled varies with the sewage, and with the method of treatment used. About .015 cubic feet of wet sludge may be expected daily in plain settling from each person contributing to the sewer. More sludge will result in chemical precipitation and about one-third less in septic tanks.

Figure 5 shows the amounts of the different constituents to be found in Kansas sewage, as compared with those found in sewage from several Massachusetts towns. Figure 6 shows the relation between bulk, weight and percentage moisture of sludge. This figure shows the importance of drying sludge before its removal.

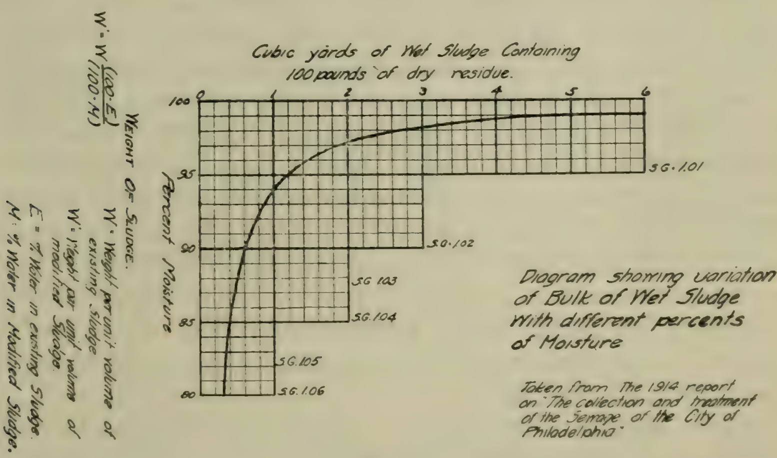


FIG. 6.

The methods which are in use, or which have been tried, for sludge disposal are:

(1) Dilution.
(2) Air drying.
(3) Mechanical drying.
(4) Application to land.
(5) Digestion in tanks.
(6) Burning.
(7) Composting with lime.

Dilution is practical only where large rivers or large bodies of water are close at hand. Generally speaking, dilution cannot be relied upon in inland districts.

AIR DRYING.

Air drying offers the best solution to the problem in the small plant. No expensive machinery is necessary and the method is extremely simple in operation. A sludge-drying bed is merely a small sand filter of such area that the sludge from one unit of the plant will cover it to a depth from one to two feet. It is necessary to have beds of sufficient number and size to allow for the cleaning of individual units at any time.

The sludge, when pumped onto the bed, contains from 80 to 95 percent water and a considerable amount of gas entrained in the mass. This gas causes the sludge to rise on the bed and allows the water to drain off the more easily.

Air drying requires from four days to two weeks. A heavy rain during the period means a setback, since partially dried sludge that has been rained on is harder to dry than the original sludge.

Some offensive odors are produced during the drying, but these are less from well-digested than from fresh sludges. When it is desired to remove fresh sludge often, a digestion tank may be used in which to store the sludge until it may be dried without offensiveness. Mechanical drying is used in a few large plants in the United States where chemical precipitation is employed, and is being considered in connection with activated sludge in order to prepare the sludge for use in making fertilizer. This method has nothing to recommend it for the small plant and will not be discussed in this bulletin.

Sludge may be disposed of by application to land in furrows, lagoons or trenches, and is dried slowly by the combined work of drainage and evaporation. Figure 7 shows the amount of sludge obtained by different methods of sewage disposal and by different methods of sludge drying.

The digestion of sludge, particularly that from plain settling

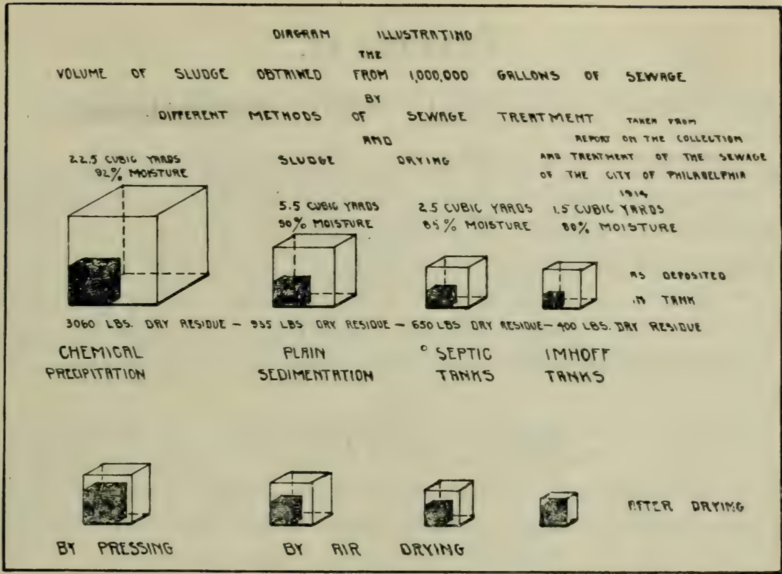


FIG. 7.

tanks, which is relatively offensive, is practiced at several plants with good results. Screenings may be disposed of in this manner very satisfactorily. The process consists merely in pumping the sludge to storage tanks, where it is allowed to digest for several months. During this time it loses some of its volume through liquefaction, becomes more compact, and is more readily handled. In the small disposal plant there is generally no need for digestion tanks, but in a few cases they may be used to advantage.

Sludge has been disposed of in some places by burning, but this practice is not general. Where it has been accomplished, pressed or dried sludge cake with a moisture content of less than 73 percent was necessary. At some German plants a pressed cake is made from sludge which finds a market at $1.75 per ton, and is used as a low-grade fuel.

COMPOSTING WITH LIME.

Sludge may be mixed with lime either immediately after removal from the tanks or after it is partially dried and rendered free from odor. This method, while relatively expensive, is very convenient at times when the drying of sludge would cause serious nuisance. In conclusion, it may be stated that sewage disposal cannot be practiced according to any fixed program. Methods must vary with different sewages and with local conditions. For this reason, definite figures have been avoided and general methods only have been given.

CHAPTER IV.

THE OPERATION OF SMALL SEWAGE DISPOSAL PLANTS.

IN GENERAL it may be said that small sewage disposal plants, such as are found in Kansas, are not considered of sufficient importance to warrant the employment of a regular corps of attendants for their operation, and while it is true that such supervision is not usually required, it is essential to the successful operation of any sewage disposal plant that it be under the care of a competent operator, who should inspect it at least once each day.

The above statement may seem self-evident and unnecessary, but it is made necessary because of the lack of attention given to nearly every sewage disposal plant in Kansas. The prevailing idea in regard to sewage disposal seems to be, "The plant is built and working, and therefore the sewage must be purified." No private company would put from $5,000 to $30,000 into a piece of machinery and then expect it to do its intended amount of work without competent attention.

The following statements in regard to plant operation are made in the light of observations carried out during two years of investigation of Kansas plants.

Sewerage Systems.

Most Kansas towns which have disposal plants are sewered on the separate plan; that is, they have a system to carry the sanitary waste of residences, factories, etc., and they have either an entirely separate system of mains and laterals to take charge of the storm water, or storm water is allowed to follow its natural course on the surface.

The wisdom of having only sanitary waste carried by the sewer leading to the disposal plant is self-evident, since the size of the plant is determined by the maximum amount of sewage to be treated. Trouble is sometimes caused in sanitary sewers by excess flow due to the entrance of storm water through roof drains, leaks in the sewer itself, or to excessive infiltration of ground water. In view of these facts it is necessary that the sewerage system have vigilant attention.

It is impractical to construct a tile sewer with cement joints that is absolutely water tight, but reasonable care in placing the jute or hemp gasket, and thorough filling of the bell of the pipe with cement, will do a great deal toward keeping down excess flow. Many sewers tributary to disposal plants have been laid without jute or hemp packing in the joints, and as a result the operators of these plants must contend with the proposition of excess flow.

Excess flow may be cared for either by the construction of extra units in the plant or by by-passing the extra flow. Fortunately, the excess flow comes generally at times of high water in the receiving stream, and hence, within certain limits, no harm is done by by-passing dilute raw sewage around the plant directly to the stream.

PROTECTION OF PLANTS.

For the protection of plants from flood water or from excess flow of sewage it is customary to use one of the following:

1. Hand-operated valves.
2. Automatically operated valves.
3. Sewage interceptors.

HAND-OPERATED VALVES.

If an attendant were at the plant at all times, hand-operated valves would furnish the best method for handling excess flow and protecting the plant from flood. By the use of such valves any amount of sewage may be admitted to the plant, or the plant may be shut off entirely. The average small plant, however, does not have continual attendance, and as a result hand-operated valves give no protection for a great part of the time.

AUTOMATICALLY OPERATED VALVES.

Valves automatically operated by floats which are moved by the rise and fall of the water in the receiving stream, or in the sewer main, are very efficient in plant protection. They are better than hand-operated valves in that they do not require constant watching. The floats may be made to operate valves at both ends of the plant, thus making it possible to cut the plant entirely out. A device of this kind completely by-passes the sewage when the water in the receiving watercourse is higher than the effluent pipe of the plant. The harm from this is in most cases compensated by the protection from back water or flood water.

LEVEES.

Unless levees are used in connection with the protecting valves, the entire plant must be water-tight. This would be impractical in most cases.

INTERCEPTORS.

When there is sufficient fall from the plant to the watercourse, in order to preclude the danger from floods, the problem of excess flow may be very conveniently handled by means of an interceptor. This is a device which allows a certain amount of sewage to flow to the disposal plant, while the remainder is sent directly to the stream.

CARE OF PLANT SITE.

As ordinarily kept up, a Kansas disposal plant is an unsightly place indeed, and it is small wonder that it is studiously avoided by every one except those whose duty it is to give it attention. Rank growths of weeds, piles of lumber, rock, poorly cared-for sludge beds, broken tile, etc., all tend to give the place a dilapidated look, whereas if the slopes were cleared of weeds and planted to grass, scraps cleared away, broken tiles replaced, sludge beds properly cared for and the entire plant kept in order, it would be an honor to the community. Plants should be well fenced in, and all openings, such as pits, basins and manholes, should be covered or fenced. The practice of pumping sludge from a tank and allowing it to spread as it may over the adjacent area is shiftless and dangerous—shiftless because with an outlay of a little work and with very little expense an adequate sludge bed may be constructed and the unsightly mass of sludge confined to a bed where it may drain properly and be cheaply and easily removed; it is dangerous because of injury to surrounding land and possible lawsuits which may arise from the nuisance which is invariably created. (See plates O S and T, pages 138 and 139.)

ATTENDANCE.

As a rule, sewage disposal plants of small cities are in charge of water superintendents, or street commissioners, men who have other duties which take up the greater part of their time. These men either visit the plant from time to time, or have one of their employees, generally a laborer, do so. In numerous cases the plant is not seen at all except on the occasion of a visit from the board of health officials. Nothing is more evident than the fact that plants under such loose management can not be operated

efficiently. Some towns have built plants seemingly with the expectation that they would produce drinking water from the sewage, and when this expectation has not materialized the plant has been rated a failure. While it is true that some plants do not give results as good as those obtained by others, still it is also true that some results can be produced by the poorest plant, with proper supervision, while without attention the best plant is worse than useless.

The importance of efficient supervision has been the subject of many papers and many talks by men who are in position to know its worth. Doctor Thresh, an English sanitation authority, said, in an address before the Association of Managers of Sewage Disposal Works: "I have so repeatedly seen excellent works give poor results on account of inefficient management, and very defective works give fair results on account of the efficiency of the management, that I have come to regard the manager as being more important than the works."

Mr. T. C. Hatton, chief engineer of the sewerage commission of Milwaukee, has been quoted as saying that, "Rather than being a drawback to the process of sewage disposal by activated sludge, the extra care and attendance necessary is really a point in its favor, since any form of sewage disposal needs attendance for its proper practice, and with other forms this may be neglected, as it has been in the past."

At present no standard of purity is set on the effluents to be obtained from Kansas plants, and therefore, it is not possible to say just when a plant is at the point of giving a barely passable effluent, but it is possible for each plant to be operated at its own maximum efficiency, and when this is done the sewage disposal problem of Kansas will be on a fair road to solution.

Septic Tanks.

ONE-STORY OR BOX TANKS.

By far the greater number of Kansas plants consist wholly or in part of a septic tank of the one-story or box type. The sewage enters the tank back of a surface baffle, and is drawn off either over a weir protected by surface baffles from scum, or through pipes which draw the effluent from below the water level in the tank. These tanks have been designed for storage periods of from twelve to twenty-four hours, and with very few exceptions are composed of two or more compartments by which the opera-

tion of the plant may be made continuous, since one compartment only need be cleaned at a time. Owing to optimistic calculations on the future population of cities and to the consequent expectation of the number of persons who will connect with the sewer system, many tanks have been built far in excess of the size most adapted to the present needs of the community, and the result is shown in many cases by oversepticized effluents. The presence of storm or ground water to some extent counteracts the effect of overcapacity, but as a rule the times of greatest nuisance from offensive effluents are when storms are few and the water level is so lowered by drouth that little or no excess water reaches the sewers.

The capacity of a tank may be lowered and its period of detention decreased very readily by building a division wall lengthwise in the tank, or a plant that is too small may have another unit or compartment added.

The proper period for the detention of sewage in a tank cannot be stated arbitrarily; it must be adapted to local conditions. Other things being equal, a shorter period will suffice in summer than in winter, since the temperature conditions in summer are more nearly those adapted to vigorous bacterial action. Eight hours will generally be sufficient in warm weather and from twelve to twenty hours should suffice in winter.

Septic action may be detected in several ways:

1. By loss of dissolved oxygen.
2. By appearance of bubbles on surface of liquid.
3. By cloudiness and periodical appearance of sludge in effluent.
4. Formation of "cesspool" odors.

SETTLING TANK.

In some cases, especially where there is danger of polluting the receiving watercourse in the immediate vicinity of the plant, it is better practice to reduce the period of detention and use the tank as a plain settling basin. By so doing the sewage remains relatively fresh and merely loses the heavier solid matter, which in sanitary sewage includes most of the putrescible matter.

Experiments made at many places show that the greater part of the settling solid matter is thrown down during the first two hours of settling and that no appreciable amount settles after five hours. (See diagram, Fig. 8.) Therefore, if the tank is to be operated as a settling basin a compartment, or preferably a pair

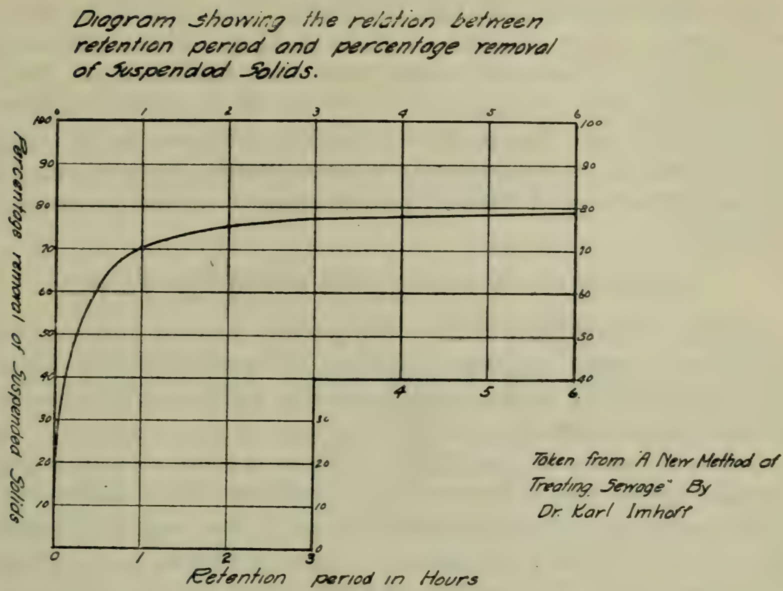


FIG. 8.

of compartments, becomes necessary in order to provide a duplicate unit for use while cleaning.

The advisability of using the tank as a septic tank or as a settling basin must be determined by the character of the sewage to be treated and by the subsequent treatment to be given the effluent. For instance, if the raw sewage reaches the plant in a fresh condition—that is, containing dissolved oxygen and having the solid matters not badly broken up and the supernatant liquid, on settling, fairly clear—the aim should be to separate the solids from the water as quickly as possible, since it is well known that the more finely divided the solid matter and the more septic the condition of a sewage, the more difficult will be the subsequent purification. On the other hand, if the plant is located at quite a distance from the city and the grades of the main sewer are slight, the sewage will reach the plant in a stale or even septic condition, and a period of detention in a tank longer than that required for the deposition of the greater part of the settling solids will merely cause the tank to produce an oversepticized effluent.

The only good to be gained from the use of a long detention period is the reduction of the volume of sludge due to compacting and to liquefaction of the solid matters. Under favorable conditions about one-third less sludge may be expected from tanks

which operate under anaërobic conditions than from those which rely merely on the principle of plain settling. This means that from a carefully operated septic tank only two-thirds as much sludge will have to be disposed of as would be the case if a settling basin were used. The problem of sludge handling in the small plant, however, is not generally a large enough item to warrant the sacrifice of a good tank effluent in order to reduce the amount of sludge.

REGULATION OF DETENTION PERIOD IN TANKS.

In the following table is given the percent removal of suspended solids and oxygen consumed effected by several Kansas tanks, and also the length of the detention period which was in operation at the time the tests were made.

Owing to operative conditions, such as need of cleaning, wide fluctuations in rate of sewage flow, disgorgement of sludge, etc., these results are not uniform and do not follow any well-defined line. They do, however, permit a few conclusions to be drawn from them as to the operation of tanks under Kansas conditions.

TABLE SHOWING OPERATION OF TANKS IN KANSAS.

Location.	Type.	Suspended solids removed, percent. Parts per million.	Oxygen consumed, percent removed, Parts per million.	Oxygen demand. Parts per million.	Detention period, hours.
Burlingame	I	35.0	0	105	13.0
Burlingame	I	81.0	0	Stable.	2.7
Burlingame	I	61.0	62.0	72	6.6
Winfield	I	44.0	36.0	315	4.0
El Dorado	P	60.0	38.0	....	7.9
El Dorado*	P	74.0	40.0	....	7.9
El Dorado	P	7.5	14.0	....	2.0
Osage City	P	0	25.0	48.0	35.0
Newton	P	39.0	43.0	56	25.0
Newton	P	30.0	23.0	60	10.5
Cherryvale	P	22.0	....	....	8.1
Cherryvale	P	84.0	34.5	....	2.5
Independence	P	0	23.0	44	7.4
Independence	P	0	13.0	....	6.2
Girard	P	11.0	0	123	18.0

I. Imhoff tanks.

P. Plain tanks.

*Liquid chlorine added before sewage entered tank.

The conclusions are:

(1) For the same sewage, long detention periods (12 to 24 hours) do not give appreciably greater percentage removal of suspended solids than do short periods.

(2) The stability of the effluent is better with the short period than with the long.

(3) Greater reduction of oxygen consumed is effected by the short periods.

(4) The amount of settling depends on local conditions to such an extent that it is impractical to compare results directly. Before results are compared, allowance should be made for—

(*a*) The character of the different sewages treated.
(*b*) The design of the tanks.
(*c*) Temperature at time of tests.
(*d*) Character of action in tank (septic or nonseptic).

It is not intended to state that more settling actually occurs in the short detention periods than in the long, but this seems to be the case, owing to the fact that vigorous septic action in the case of the long period causes the formation of gas in the deposited sludge, which gas, on rising to the surface, often carries particles of sludge with it. Thus the tests on the effluent sometimes show solid matter which has once been deposited. The same is true of tanks which have a short period of detention, but which have been allowed to fill with sludge until a thick layer is formed on the bottom of the tank in which septic action takes place.

The following table is given to show the percentage removal of suspended solids as brought out by actual practice at some plants in this country:

RELATION OF DETENTION PERIOD TO REMOVAL OF SUSPENDED SOLIDS.

Detention period, hours.	Percent removal suspended solids.	Authority for test, and where test was made.	Kind of tank.
8 6	80 77	Metcalf & Eddy, Gloversville, N. Y., 1908-'09	Plain horizontal flow.
20.8 15 12 10 8 6	41 49.8 47 56 55 66	Metcalf & Eddy, Worcester, Mass., 1902-'03	Plain horizontal flow.
.8 1.7 2.5 3.3 4.2	35 50 55 57 60	Geo. A. Johnson, Columbus, Ohio, 1905	Plain horizontal flow.

The settling of solids in sewage has been worked out very carefully by Doctor Imhoff of the Emscher Drainage Board, Germany, and the results of his test are shown in Figure 8, which is a curve

representing the percentage removal at different detention periods. It will be noticed that the Columbus results follow this curve approximately, but that the Worcester results do not show the effect of the longer detention period.

Doctor Imhoff gives the following weights to the factors operating in a settling tank.

Factor.	Importance.
1. Detention period	100
2. Change in temperature	30
3. Depth of tank	30
4. Construction of inlet and outlet	30
5. Character of sewage as fresh or septic domestic or manufacturing waste	30
6. Velocity of flow through tank provided it is less than 350 to 600 feet per hour	0

INLETS AND OUTLETS.

Care must be exercised to prevent scum from forming in the inlets or outlets of tanks. In case curved pipes are used, the lower ends should be submerged to a depth that will allow them to discharge the sewage and collect the effluent below the level of the scum, and yet not deep enough to cause disturbance of the settled sludge. In some cases it may be necessary to alter slightly the design of the inlets and outlets in order to prevent accumulations.

CLEANING.

The length of time that any plant may operate without being cleaned depends entirely on local conditions. Some tanks have been in operation for two or more years, and the sludge deposit is not yet large enough to warrant its removal, while others fill with sludge so rapidly that it is necessary to clean them two or three time each year. Where sludge cannot be removed by gravity, the tank should be cleaned when the detention period has been cut down from 10 to 20 percent. Weather conditions should be taken into account in choosing the time of cleaning, for it is desirable to dry sludge as quickly as possible and remove it before rains undo the work of drying.

APPEARANCE OF SLUDGE IN THE EFFLUENT.

All plain septic tanks disgorge sludge from time to time and must be watched closely to prevent the fouling of the receiving watercourse or the clogging of the secondary treatment units.

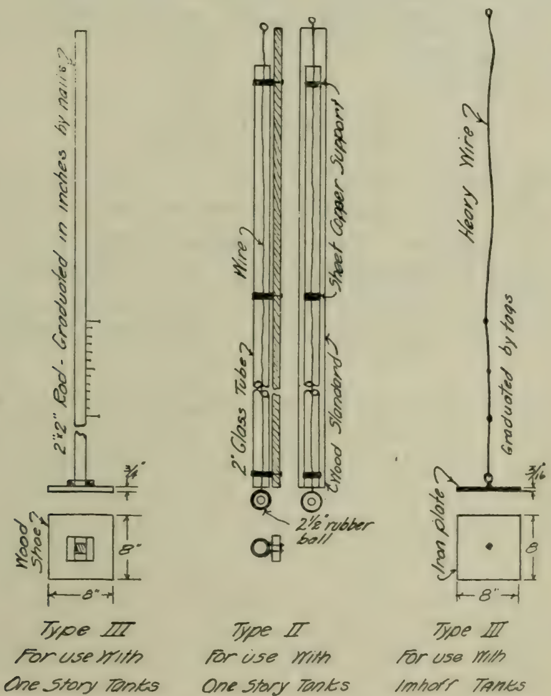
Sludge in the effluent of a tank may mean one of several things, viz.:

1. Need of cleaning.
2. Long detention period.
3. Poor arrangement of baffles.

The plant operator, if he pays attention to the operation of his tanks, will soon learn to locate the trouble and remedy it, unless, of course, it is due to some defect in plant construction.

SLUDGE MEASUREMENTS.

Frequent measurement of the depth of the sludge deposit is important, since this is the best means of knowing the capacity of the tank at any time. The devices shown in Figure 9 are convenient for this purpose.



DEVICES FOR SLUDGE MEASUREMENT

FIG. 9.

DISINTEGRATION OF CONCRETE WORK.

At several plants it has been noticed that the concrete which forms the top and sides (above the water line) of septic tanks, or dosing chambers, has become soft and chalky for a depth of from one-fourth to one-half inch. Presumably this is caused by the action on the concrete or sulphuric acid which may be formed by the action of a type of sulphur bacteria on the hydrogen sulphide produced by the decomposition of the sewage. Just how deep this disintegration may be carried is not known, but wherever it is encountered steps should be taken to arrest it. It is known that if the detention period in both dosing chamber and tank were shortened to such an extent that septic action would not take place, the production of hydrogen sulphide gas would not occur, and therefore the sulfuric acid would not be formed. This statement is made on the strength of the fact that the above condition has always been found in tanks and dosing chambers which have long detention periods.

Two-Stage Tanks.

The settling sewage is isolated from the digesting sludge in the two-story tank. The Imhoff tank is the only example of this type to be found in Kansas. There are several tanks designed by the Lewis & Kitchen Company that might be called two-stage tanks. However, these will not be discussed in this connection, since settling and sludge digestion do not take place in different compartments.

Considerable care must be exercised in the operation of the two-story tank. Gas vents must be kept open to prevent the entrance of gas-lifted particles of sludge into the settling chamber. Scum should be removed from the surface of the settling chamber frequently in order to prevent its decomposition, with the resulting pollution of the effluent. The height of the sludge in the digestion chamber should be so regulated that its surface will at no time be higher than a foot or so below the lowest point of the settling chamber. One great advantage of the two-stage tank is the fact that sludge may be removed by gravity, and the sludge pipes and valves should be tested frequently to see that they are in working order.

The failure to keep a sludge pipe open caused several days' labor at one of our plants, and it was very disagreeable labor, too. The sludge pipe in this was not straight and entered the

tank at the bottom through a curve. It was necessary to force a fire hose down through this pipe and literally blow the sludge out of the "U" shaped pipe at the bottom of the tank before the sludge would flow. Most of the installations of this type are provided with straight pipes open at one end, which arrangement allows for rodding in case clogging occurs. The settling chambers of Imhoff tanks should be provided with scum boards to prevent floating solids from being carried over with the effluent.

Good results were obtained at one of the plants by damming the effluent weir and inserting two curved pipes which draw the effluent from a point twelve inches below the surface. The construction of this plant precluded the insertion of a scum board.

If the sewage contains rags, grit, garbage, or anything that is liable to clog the inlets, outlets, or sludge pipes, or which is liable to form a hard, nonflowing sludge, these materials should be removed by suitable screens or grit chambers before the sewage is let into the tank. As in the case of the one-story tank, it is impractical to set an optimum detention period for all two-stage tanks; its selection must be the result of repeated trials of each plant, and in many cases it is dependent on the construction of the plant.

Contact Beds.

The condition of the sewage to be treated on a contact bed plays a very important part in determining the character of the effluent, and the first thing to be considered in this type of treatment is the operation of the primary units. All of the Kansas contact beds treat the effluent of tanks which operate either as septic or plain settling tanks, and therefore tank effluent will be meant when the influent of a contact bed is mentioned. Experience in the operation of our plants shows that better results may be expected from beds which treat relatively fresh tank effluent, and the writers have yet to see a stable effluent produced by a bed which treats the effluent of a tank having a detention period of more than twelve hours. The operation cycle of a contact bed should receive careful attention and should be chosen for each plant only after several trials. The cycle is composed of four parts, viz:

(1) Time of filling the beds.
(2) Time of contact.
(3) Time of emptying the beds.
(4) Time of rest between doses.

In all plants operated from dosing chambers the time of filling is fixed by the size of the pipes leading from the chamber to the beds; and in like manner, the time of emptying beds, which are operated by means of timed siphons, is fixed by the size of the outlet pipes.

Therefore, in plants of this character the adjustment of the operation cycle must be made either in the time of contact or in the capacity of the dosing chamber. The first is easily accomplished by opening or closing the valve leading to the timing chamber of the timed siphons, and the second may be effected by either increasing or diminishing the head of water necessary to force the operating siphons in the dosing chamber. In case of plants which are operated by continuous-flow devices, the time of filling depends on the flow of sewage, and the regulation of the operation cycle can be made in the contact period only.

It is impossible to set a certain amount of time for the different operations of the cycle, since local conditions vary so widely. The proper adjustment will be reached only after considerable experimentation and study on the part of the plant operator. This is one of the points where operation may make or break a plant.

As a rule, fresh-settled sewages may be dosed to a contact bed with a shorter resting period than that allowed septic sewage. It is advisable, however, to allow a period of rest at least three times as long as the combined operations of dosing, contact, and draining for any type of sewage.

THE PERIOD OF CONTACT.

This period should not be over one hour for any except very fresh sewage, and in most cases thirty minutes will suffice. It is now considered that the greater part of the nitrification process takes place during the resting period rather than in the contact period, and hence, within certain limits, the sooner the sewage is out of the bed the better.

BALLAST.

When new, the ballast, if broken evenly, should contain from 40 to 50 percent voids. These voids, however, fill up gradually, and it is necessary eventually to remove the stone and clean it by washing or screening before replacing it in the beds. The time of cleaning depends upon the rapidity of the clogging, and since the process is expensive and tedious, it is well to remove as much as possible of the solid matter from the sewage before it reaches the beds.

Some of the Kansas beds have been in operation for six or seven years, with not enough clogging to hinder operation, while others have become clogged in less than one year, all due to differences in operation and care.

DOSING APPARATUS.

It is impractical in a bulletin of this size to take up a detailed description of the many types of control apparatus in use for the operation of contact beds, sprinkling filters, sand beds, etc.; but since the efficiency of the plant depends so much on their operation, their care constitutes much of the plant operator's duty, and a short chapter will be devoted to a description of the types used in Kansas.

With very little trouble, a blue print or drawing of the particular set of apparatus may be prepared, framed and hung at the plant, where it will always be at hand when repairs or changes are made. Blue prints or diagrams of standard apparatus may be had for the asking of the manufacturing companies. Under some conditions, particularly in dosing chambers which handle oversepticized effluent, the piping of the apparatus disintegrates very rapidly and must either be replaced by piping of a more resistent metal or preparations must be made for frequent renewal. In case the latter plan is followed it is best to have at the plant the necessary piping cut up for a complete renewal and ready to be installed at any time. At one of our plants where trouble occurred by disintegration of iron piping, good results were obtained by the substitution of brass pipe.

The attendant should be on the lookout constantly for air leaks and stoppages, and he should have the necessary tools at hand for the removal of any part of the apparatus. Since the sewage is generally septic or is becoming so, the time that is required to fill the dosing chamber should be as short as possible. A number of small secondary treatment units rather than a few large ones is recommended. In several cases the size of the dose, and consequently the period of filling the dosing chamber, has been cut down, with a resulting increase in effectiveness of the contact beds. Occasionally sedimentation takes place in the dosing chambers, causing a foul deposit, which should receive frequent attention and removal. As a rule, such conditions are due to imperfect control of the settling or septic tanks, and indicate a necessity for removal of sludge.

RESULTS TO BE EXPECTED FROM CONTACT BEDS.

The results of the tests on Kansas contact beds are discouraging, since generally they do not show a marked improvement over the tank effluent which was treated. The reasons for this are:

(1) The beds tested had been operating from one to five years without adequate supervision.

(2) There was no arrangement for properly gauging the operation of the beds; that is, for protecting them from excess flow, etc.

The results shown in the appendix are therefore not to be considered typical of what the beds may do if properly operated.

Trickling Filters.

What has been said of the contact bed is also true of the trickling filter, for as far as principle is concerned, they are identical. However, in the case of the sprinkling filter there is the added necessity of keeping the sprinkling nozzles clean and taking care of the distributing apparatus, etc. It is often advisable to provide a final settling basin for contact bed or sprinkling filter effluents, because solid matter will from time to time be washed out and carried away by the effluent. A detention period of thirty minutes will generally suffice for this settling and not give sufficient time for putrefaction to begin. The later installations of trickling filters are provided with means for flushing the filtering material. This should be done as often as is necessary to prevent clogging of the ballast.

Sand Filters.

This type of treatment is probably the most complete in regard to purification in general use at the present time. A well-designed and well-operated sand filter should produce a perfectly clear and stable effluent with a bacterial reduction of 98 to 99 percent. The same general rules apply as in the case of the contact bed or trickling filter. On account of the size of the grains, most of the decomposition of solid matter will be accomplished on the surface or in the first inch or two of the sand, and the attendant should be constantly on the lookout for clogging and ponding. Air must be allowed to enter the body of the beds if a stable effluent is expected, since the desired biological action is essentially aërobic, and therefore the action of the filter must be intermittent. In other words, the sewage must be applied in doses with a period of rest intervening. The proper cycle of operation is as in the case

of the contact bed, a point to be arrived at through a thorough study of local conditions and cannot be arbitrarily set. If possible, the surface of each bed should be allowed to dry between doses, but if this is not possible, each bed should be allowed at frequent intervals to stand idle for several days.

DRAINAGE.

Good drainage is essential, since it is necessary that the sewage be not allowed to remain in the beds long enough to become stale, and since the capacity of the beds is largely determined by this point.

LEVELING.

The beds should be level to allow all the surface to be dosed simultaneously and properly to distribute the work of the bed. The surface also should be kept smooth in order to allow for cleaning the beds with a minimum loss of sand. Raking the beds from time to time will tend to keep the surface clean and aid aërobic bacterial action by allowing more ventilation.

FILLING.

The sewage should be allowed to enter the beds as rapidly as possible without disturbing the surface of the sand. Too slow a rate of filling will allow the greater part of the sewage to percolate through that part of the sand near the inlets and will result in the overdosing of this part of the bed. If there is a tendency to scour at the inlet points, small platforms of wood may be used to break the velocity of the sewage.

TREATMENT ON SOIL.

The same general conditions operate in case natural soil is used for disposal, although the rate of treatment is very much slower.

Weeds, grasses, etc., will grow profusely on sand filters and irrigation areas, and if not kept down will interfere seriously with the success of the treatment both by shutting out air from the bed and by clogging the underdrains with roots. If vegetation is carefully kept down from the start it is a very simple matter to prevent its spread, but, on the other hand, if it is left without care for any length of time, elimination is a very difficult problem.

Growths of algæ or fungi are sometimes encountered in the operation of filters, and should be destroyed by allowing the bed to dry thoroughly between doses, or by allowing it to stand idle

until the growths have died out. If this method is not effective, copper sulphate or chloride of lime may be used. These chemicals should be used carefully, since it is not desirable to kill out the nitrifying bacteria in the body of the bed.

COLD WEATHER OPERATION.

It has been the practice in some of the Northeastern states to furrow sand beds in winter, thus allowing the layer of ice formed to be supported by the ridges, thus preventing the freezing of the entire bed. Kansas winters are so mild that this is not necessary, and very seldom will a bed freeze so deep between doses that the warmth of the incoming sewage will not thaw it out. However, if a bed does become frozen to a considerable depth it should not be operated until it is thawed out completely.

Subsurface Irrigation.

This method, owing to the large area required, has little to recommend it for the disposal of city sewage, but it is often a very satisfactory method for residences or for small communities. Nothing but dry, well-drained, porous soil will suffice for this purpose, and the location of the area with respect to wells should be given attention.

The sewage should be applied in doses to several distinct areas alternately, and in the same amounts as could be dosed in case surface irrigation were practiced. Distribution pipes should be located as near the surface as is practical to allow for ventilation.

Disinfection.

Disinfection plants, in comparison with other plants for bacterial removal, are cheap and easily installed, but on account of the very fact that they are relied upon to kill bacteria, they must at all times receive sufficient attention to insure their continuous operation. Sand filters, for instance, will operate for a long time without care and will give at least a small percentage of their normal efficiency, but in the case of a disinfection plant the operation must at all times be up to standard or the plant is of no use. Therefore, in this process, slipshod methods of operation are more dangerous than in any other method of sewage disposal. Hypochlorite of lime, or bleaching powder, and gaseous chlorine are the only chemicals used in Kansas for the disinfection of sewage, and

these are probably the most efficient agents for this purpose. The following statements will apply only to these. When figures are based on amounts of available chlorine, the relative efficiency of the two as disinfectants is the same.

No attempt should be made to disinfect sewage which contains large floating or settling solids, because the chlorine will not penetrate these bodies, and as a result some of the bacteria will not be affected. Only well-screened or settled sewage should be disinfected.

MIXING.

Thorough mixing is important to insure the complete solution of the disinfectant. This may be accomplished by agitation either by mechanical apparatus or by allowing the treated sewage to flow through a baffled channel. After the addition of the chemical, the sewage should be held in contact with it for a period of from one-half to two hours to allow time for the action on the bacteria. If the sewage is discharged into the receiving stream immediately after receiving the dose of chemical, many of the bacteria are not killed, and on reaching the stream the disinfectant becomes so diluted that it has no further effect.

METHODS OF FEEDING.

The solubility of chlorine gas permits the making of a five percent solution, but better practice is to use weaker solution—say one or two percent—because there is less loss of chlorine from a solution of this strength than from one almost saturated. Dilute solutions may be fed more accurately also.

In the use of gaseous chlorine, the feeding device consists of a meter to register the flow of gas, and some type of absorption apparatus in which the chlorine is mixed with water. By varying the water and the chlorine feeds, the strength of the solution may be varied and the solution may be fed directly to the sewage.

When bleaching powder is used the chlorine must be leached out of the powder and the excess lime settled out of the solution before it is used. Bleaching powder, as it is found on the market, contains from 30 to 35 percent available chlorine, by weight, and this must be considered when preparing solutions. Owing to loss in storage, etc., the bleach should be used in excess of the theoretical amount necessary for the strength of solution desired. It is safe, however, to consider the fresh chemical as containing 30 percent available chlorine.

The solution is fed usually through a standard orifice box, which is a small tank fitted with a narrow slit, the length of which may be varied to allow the desired amount of solution to flow through. Orifice boxes give excellent results with proper care, but need frequent cleaning to prevent the incrustation of the orifice due to deposition of lime from the solution. This incrustation should be removed with acid rather than by scraping, since there is danger of enlarging the orifice.

Metal piping which is used for carrying chlorine solution is subject to rapid deterioration, and spare fittings for the complete chemical line should be on hand at all times. Lead or brass pipe is not so quickly destroyed as is iron, but its higher price is hardly justified, owing to the cheapness of the iron pipe.

Particular care must be exercised to prevent leakage in the use of gaseous chlorine, since in addition to being a strong corrosive agent, chlorine is a very poisonous gas. The joints of meter and piping should be tested frequently for leaks by bringing close to them an open bottle of common household ammonia. In case of leakage a dense white cloud of ammonium chloride is formed.

The amount of chlorine to be used depends upon the character of the liquid treated and on the degree of disinfection desired. The amount will vary from 15 parts per million in the case of strong sewages or tank effluents, to 3 parts per million in the case of good contact bed effluent.

Sludge Disposal.

Although this phase of the disposal problem is not so pressing in small plants as in large installations, yet it must receive attention, and no disposal plant is complete without adequate means of handling and disposing of sludge and debris from various parts of the plant. The mere fact that a plant is equipped with a sludge bed is not a complete solution of the problem. Some of our plants have been so poorly managed that the sludge bed has become a wreck before it was used for sludge drying. Banks have been allowed to cave in and weeds take possession of beds in numerous cases, necessitating further expenditure by the owners of the plant before efficient operation could be expected. Some of our plants are not equipped with any kind of sludge disposal facilities whatever, and the carelessness shown in getting rid of the sludge is discouraging. In some cases the sludge is pumped into the effluent channel of a tank and allowed to flow into the receiving water-

course. In others the sludge is pumped from the tank and allowed to flow broadcast over the surface of the ground near the plant, regardless of the nuisance which it invariably creates.

The air-drying method for sludge disposal will be the only one discussed here, since, all things being considered, it is the most practical for Kansas plants. This method is extremely simple, but requires care and judgment in order that good results may be obtained.

Tanks should not be cleaned unless there is evidence of a week or so of good weather, since sludge that has been exposed to rain while drying is much harder to dry than fresh sludge. When the sludge has become dry enough to be spaded it should be removed from the bed and the surface prepared for another dose. The dried sludge should be removed from the vicinity of the plant and either dumped in an out-of-the-way place or disposed of to farmers for fertilizer.

Tile distributing pipes are of no practical use on the surface of a sludge bed, and during cleaning are merely in the way. All that is necessary in the way of a distributor is a platform to break the velocity of the incoming sludge and to prevent it from scouring the bed. For the benefit of plant operators who wish to provide their plant with sludge beds, a diagram of a very convenient form of bed is given here. The bed should be located low enough to allow the sludge to be removed from the tank by gravity but if this is impossible, the higher the bed the better, on account of the expense of the deeper bed and danger from floods.

The drain pipe from the bed may be connected to the main effluent pipe from the plant if convenient, but in all cases the bed should be protected from backwater by the insertion of a valve in the outlet line and by construction of levees.

The concrete curb around the bed is important, since earth banks cannot be prevented from slipping down into the bed, and the cost of their cleaning will soon amount to more than the cost of the curbs. (See Plates R, U, V and W, pages 139 and 140.)

Control of Plants.

In another chapter the methods in general use for the control of the operation of sewage disposal plants, by means of experimental work, have been outlined. These tests, if followed fully, require the attention of experts, and this is not to be considered for the small plant. Some tests are absolutely necessary for the

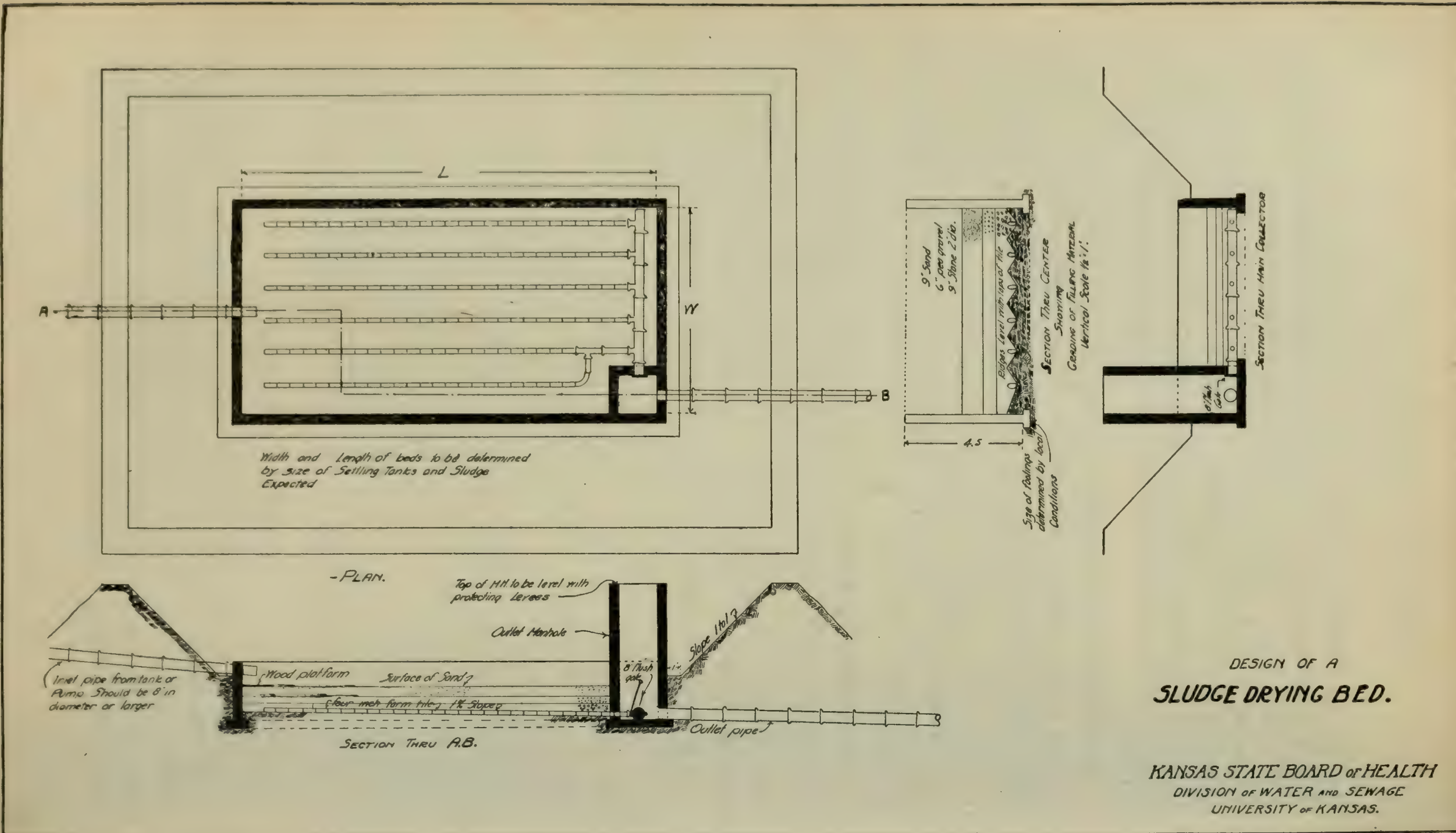

L
W
A
B
Width and Length of beds to be determined by size of Settling Tanks and Sludge Expected
-PLAN.
9" Sand
6" pea gravel
9" Stone 2" dia.
Ridges Level with tops of tile
SECTION THRU CENTER
SHOWING
GRADING OF FILLING MATERIAL
Vertical Scale ½":1'.
4.5
Size of footings determined by local Conditions
8" Flush Gate
SECTION THRU MAIN COLLECTOR
Top of M.H. to be level with protecting Levees
Outlet Manhole
Slope 1 to 1½
Inlet pipe from tank or Pump Should be 8" in diameter or larger
Wood platform
Surface of Sand
8" Flush gate
four inch farm tile
1% Slope
Outlet pipe
SECTION THRU A.B.
DESIGN OF A
SLUDGE DRYING BED.
KANSAS STATE BOARD OF HEALTH
DIVISION OF WATER AND SEWAGE
UNIVERSITY OF KANSAS.

FIG. 10.

successful operation of any plant, and the following plan is suggested for operators of Kansas plants.

First. Provision should be made by the city council or board of commissioners for the daily visitation to the plant by one man. The total time of one man need not be devoted to this, but he should do what work is necessary.

Second. This man should be provided with apparatus for making the settling solids and the relative stability tests as outlined in the chapter on chemical control of plants.

Third. A complete log of the plant should be kept by the operators, on blanks furnished by the State Board of Health, and copies of these logs should be sent to the engineer of the State Board of Health weekly. A sample of the data sheet is given below.

The effect of this work will be to make more positive the help of the Engineering Department of the State Board of Health, to the plant operators, and it will also serve as a check on plant operation by which the operator may base his own actions.

General.

In this chapter suggestions that will be of aid to the operator of any of our plants have been attempted. There is full realization that local conditions control the operation to such an extent that definite statements are impossible. It is because of this fact that each plant should be in the hands of a man who is capable of working out, for himself, the problems which come up constantly in its operation.

DATA SHEET FOR DISPOSAL PLANTS.

Plant at.., *Kan.* *Week ending*..................*19*........

RESULT OF TESTS.

Sample.	Date.	Hour.	Temperature.		Stability.		c.c. used.	Settling solids, c.c sediment.					Remarks.	Sewage. flow.
			Air.	Sample.	Dilution.	Figure.		30 min.	1 hr.	2 hrs.	5 hrs.	24 hrs.		

MARKS: R=raw sewage; S=tank effluent; C=contact bed effluent; T=sprinkling filter effluent; D=disinfected; F=sand filter.

DAILY LOG.

SUNDAY..

....

....

....

MONDAY..

....

....

....

TUESDAY...

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....

....

WEDNESDAY..

....

....

....

THURSDAY..

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....

FRIDAY..

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....

....

SATURDAY..

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....

....

GENERAL...

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....

....

TESTS.

Samples of raw sewage and of the effluents of the various tank beds, etc., should be taken at least twice weekly, and tests for relative stability and settling solids run on these.

RELATIVE STABILITY.

Fill a 4 oz. bottle to overflowing, add 1 c.c. methylene blue solution. Insert cork and let stand at room temperature till the blue has faded out. Record number of days to change the color.

RELATIVE STABILITY TEST.

A sewage may be called stable when the contained organic matter has taken such a form that it is not capable of undergoing offensive putrefaction.

Relative stability is the ratio of the available oxygen in the sample to the amount required to render it stable.

A stability figure of 75 means that the sample contains 75 percent of the oxygen necessary for stability.

The following table gives the stability figures for different periods.

The figures for incubation at 20° C. should be used unless special apparatus for incubation is employed.

For effluents of extremely low stability, dilutions should be made in aërated water and the relative stability of the mixture noted. A few trials will be necessary before the proper dilution may be detremined.

t^{20}	t^{37}	S	t^{20}	t^{37}	S
0.5	...	11	8.0	4.0	84
1.0	0.5	21	9.0	4.5	87
1.5	...	30	10.0	5.0	90
2.0	1.0	37	11.0	5.5	92
2.5	...	44	12.0	6.0	94
3.0	1.5	50	13.0	6.5	95
4.0	2.0	60	14.0	7.0	96
5.0	2.5	68	16.0	8.0	97
6.0	3.0	75	18.0	9.0	98
7.0	3.5	80	20.0	10.0	99

S=relative stablity or ratio of available oxygen to oxygen required for equilibrium. Expressed in percent.
t^{20}=time in days to decolorize methylene blue at 20° C.
t^{37}=time to decolorize at 37° C.
Theoretical relation: S=100(1-0794 t^{20}). S=100(1-630 t^{37}).

SETTLING SOLIDS.

Place 1,000 c. c. of sample in settling glass and allow it to remain quiet. Record c. c. of sediment in bottom of glass at the end of 30 minutes, 1 hour, 2 hours, 5 hours and 24 hours from time of filling the glass.

This test approximates the action in a settling tank, and a comparison of the effluent of a tank with a sample that has had a settling period in a glass of equal length to the detention period in the tank, gives a good check on the operation of the tank.

KEEPING THE LOG.

Everything that has the least relation to the operation of the plant should be recorded.

The following must receive attention daily: (1) Time at plant; record extra help. (2) Reading of the measuring weir or device for measuring flow. This *must* be recorded, with the time of reading.

The following must be recorded each week: (1) Condition of valves, inlets, automatic siphons, by-passers, etc. (2) Thickness of scum and sludge. (3) Condition of receiving watercourse. (4) Operation cycle; number of units in use, etc.

In addition to the above, records should be kept of all abnormal condition of the effluent, such as unloading of sludge, bad odors, etc., and of cleaning tanks, removal of dried sludge, cleaning beds, cutting weeds, repairs, breakdowns, and in fact everything out of the ordinary routine of the plant.

Any special device or method evolved or used should be completely described either on this sheet or on a separate sheet.

FINAL.

A carbon copy of this sheet should be kept and the original sent to the Division of Water and Sewage, Kansas State Board of Health, Lawrence, Kan., each week.

CHAPTER V.

THE CONTROL OF PLANTS BY MEANS OF PHYSICAL, CHEMICAL AND BACTERIOLOGICAL TESTS.

WHILE it is not proposed to discuss in detail the chemistry and bacteriology of sewage disposal, an explanation of the significance of the different standard tests will not be out of place here. The methods of analysis used in this work are typical of the latest developments in analytical methods as applied to sewage work. In the latter part of this investigation some of these methods were modified and improved so as to meet local conditions, but these changes in methods of analysis were made only after a sufficient number of comparative studies had been made to prove the feasibility of modifying the technique.

The standard method of expressing results of sewage analysis is in parts per million—that is, one pound of the substance in question in one million pounds of sewage. Bacterial results are expressed as the number of bacteria per cubic centimeter of sewage.

SAMPLING.

Sewage varies in strength and volume through the day, and is also subject to weekly, monthly, and even yearly variations. In order to interpret an analysis it is necessary to have a complete record of the conditions under which the sample was taken and also the conditions under which the plant was running at the time of the sampling.

Probably the most accurate method of obtaining a representative sample is to collect separate samples at half-hour periods during twenty-four hours, and the same time recording the sewage flow. Part of each of these samples proportionate to the flow at the time of sampling is poured into a large bottle, and the final sample constitutes an average sample for the day. Weekly samples may be made up in the same manner from proportionate parts of the daily samples. Since sewage is extremely unstable, it is necessary to sterilize samples which cannot be analyzed immediately. For this purpose chloroform, mercuric chloride, formaldehyde or strong acid is used. The amount of disinfectant necessary depends on the strength of the sewage and should be determined by trial.

The above method is practical only in large plants equipped with a well-organized laboratory force, and when small plants are considered it is necessary to collect fewer samples and use a correction factor in the computation of results. A convenient method for sampling at irregular intervals is that used in making the tests on Kansas plants during the last two years. It is explained in the Introduction, page 7.

ENUMERATION OF TESTS. The tests usually made in the complete analysis of sewage are:

- (1) Physical tests.
  - (*a*) Sewage flow.
  - (*b*) Turbidity.
  - (*c*) Settling solids.
  - (*d*) Solids (by weighing).
    - (1) Suspended.
      - (a) Volatile.
      - (b) Nonvolatile.
      - (c) Total.
    - (2) Dissolved.
      - (a) Volatile.
      - (b) Nonvolatile.
      - (c) Total.
    - (3) Total.
      - (a) Volatile.
      - (b) Nonvolatile.
      - (c) Total.
- (2) Chemical tests.
  - (*a*) Nitrogen.
    - (1) Total organic.
    - (2) Free ammonia.
    - (3) Albuminoid nitrogen.
    - (4) Nitrites.
    - (5) Nitrates.
  - (*b*) Oxygen.
    - (1) Dissolved.
    - (2) Consumed.
    - (3) Biochemical demand.
  - (*c*) Relative stability.
  - (*d*) Chlorine.
  - (*e*) Fats.
  - (*f*) Miscellaneous tests for special conditions.
- (3) Bacterial and biological.
  - (*a*) Total count on agar at 37° C.
  - (*b*) Red colonies on lactose-litmus agar at 37° C.
  - (*c*) Colonies on gelatine at 20° C.
  - (*d*) Microscopical analysis for plant life, etc.

Physical Tests.

SEWAGE FLOW.

The accurate gauging of sewage flow is very important, since to operate a plant, or record its operation intelligently, one must have a definite idea of the amount of sewage treated. Methods of gauging the sewage flow are given in Chapter I.

TURBIDITY.

Turbidity in an effluent from a tank or from a contact bed is almost always due to organic matter in a colloidal state, so this test may be used as a check on the removal of colloidal matter. It is usually determined by a candle turbidimeter.

SETTLING SOLIDS.

An approximation of the amount of solid matter capable of being settled out of the sewage in a certain length of time is obtained by the use of the Imhoff cone. Glasses of several different shapes have been used for this purpose, but for ordinary work the shape shown in Figure 11 is probably as efficient as any. To use this glass, fill to the 1,000 cc. mark with sewage, allow to settle, and record the amount of solid matter in the bottom of the glass at 20-minute intervals for the first two hours, at hourly intervals for the next two hours, and finally at the end of twenty-four hours.

The action of a settling basin may be checked conveniently by allowing a sample of the raw sewage to settle in the tube for the length of the detention of the tank, and comparing the supernatant liquid with a sample collected from the outlet of the tank.

Effluents may be compared with influents by filling separate glasses with samples from the different tanks, contact beds or filters, and after allowing them to settle for a certain length of time, reading the amount of sediment deposited.

Care and good judgment are required in the use of these glasses, since the surface of the settling matter will seldom be horizontal, and the true height must be estimated by an average of readings on different sides of the glass. Sometimes a correction for the true zero point is necessary, owing to the formation of gas bubbles in the lower part of the tube.

Figure 11 shows three types of settling glasses. Two glasses of the type B were used in making tests on Kansas sewages and did not give very good results because the sewage did not settle evenly in the bottom of the tube. To overcome this difficulty the type C was designed. The narrow tube at the bottom permits of more accurate reading of solid matter and the cork at the lower end allows the glass to be easily cleaned.

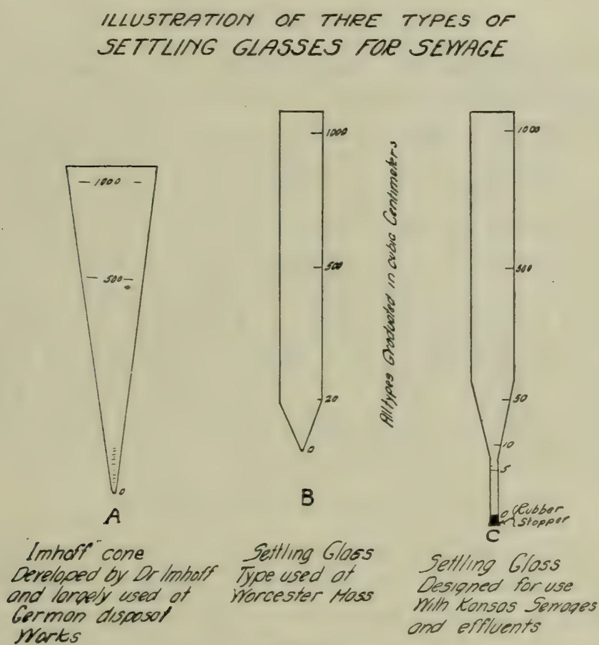

FIG. 11.

SOLIDS.

The test for solid matter is divided into nine divisions in order to eliminate constant quantities, such as dissolved solids, and to separate roughly the mineral matter from the organic matter. If all the mineral matter in sewage were nonvolatile, this test would furnish a very accurate and easily applied method of determining the total organic matter. But since some of the mineral matter is volatile, the calculation of organic matter from volatile solids cannot be determined unless sufficient data is at hand to show the percentage of volatile mineral matter present.

The amount of dissolved solid matter remains largely unchanged

in the passage through the disposal plant, though it may increase slightly, owing to organic matter going into solution. The suspended solid matter is generally made the basis of efficiency tests on plants, since the greater part of the objectionable matter in sewage is in this state.

Chemical Tests.

NITROGENOUS MATTER.

The nitrogen in crude sewage may be either unoxidized or oxidized. The unoxidized nitrogen is determined as organic nitrogen, represented by the undecomposed compounds of nitrogen; and as ammonia, represented by the amount of nitrogen present as an ammonium salt, which has been formed by the decomposition of the organic matter by bacterial action. The oxidized nitrogen is determined as nitrites and nitrates. Since a great majority of living matter contains nitrogen, the determination of this substance is the most accurate method of arriving at the amount of organic matter present. Some organic substances, of course, do not contain nitrogen, but as a rule these do not give the offense on decomposing that is caused by nitrogen compounds, and hence their removal is not so important.

TOTAL ORGANIC NITROGEN.

The Kjeldahl total nitrogen determination was used in this investigation rather than the albuminoid nitrogen determination. The percent of nitrogenous matter which is ammonia-forming is decidedly variable, and for this reason albuminoid nitrogen results are less valuable than the total nitrogen as determined by the Kjeldahl method. During the first few months of the investigation the usual Kjeldahl method was followed. The sample was digested with sulphuric acid, neutralized, distilled and Nesslerized. At the same time, tests were run in conjunction with the routine tests in an endeavor to obtain concordant results by direct Nesslerization of the ammonia formed by the distillation of the digestate. The results of this method for the direct Nesslerization have been published and may be found in the *Journal of Industrial and Engineering Chemistry.**

Methods for determining the nitrogen in the Kjeldahl process by direct Nesslerization had been advocated previous to the work

*A Modification of Whipple's Method for Organic Nitrogen in Sewages. Jr. Ind. & Eng. Chem., Vol. 8, No. 6, June, 1916, p. 499.

done in this laboratory, but the methods as advocated did not give concordant results on Kansas sewages.

The English methods as described by Fowler, Rideal and McGown were either so tedious as to make them impractical for routine work, or did not give satisfactory results. One of the great difficulties met with by chemists in the direct Nesslerization of the sewages for total nitrogen has been the turbidity of the sample in the Nessler tubes. This difficulty has been ascribed to various conditions. McGown says that calcium salts cause turbidity in the Nessler tubes. Kimberly attributes turbidity to calcium and magnesium salts, while Whipple claims that magnesium salts cause the difficulty. Perhaps it was because none of these disturbing elements were present in large enough quantities in the sewage of the eight disposal systems studied; at any rate, practically no turbid tubes were found during the investigation. This fact eliminates from the direct Nesslerization of Kansas sewages one of the problems that has been very important in the direct Nesslerization of the sewage from other localities. Of the proposed methods used up to the time of the investigation, the one suggested by Leland Whipple seemed the most feasible for the sewages of this locality.

It was found that by the addition of 10 cc. of a 10 percent solution of copper sulphate, quicker and more complete digestion resulted. The copper sulphate acts as a catalytic agent, and while no better results were obtained by using 10 cc. than 2 cc., the time of digestion was shortened. Instead of filtering the mixture of digestate and sodium hydroxide solution and then Nesslerizing immediately, the following procedure was worked out and gave the best results for Kansas sewage.

Digest 100 cc. of sample in a pear-shaped flask with 5 cc. of concentrated sulphuric acid and 10 cc. of a 10 percent solution of copper sulphate until sulphur trioxide fumes are given off and the liquid in the flask is clear. Add 20 cc. of water, a few crystals of potassium permanganate, and make up to 250 cc. Pipette 25 cc. into a 100 cc. Nessler tube, add 25 cc. of a 5 percent solution sodium hydroxide solution and make up to 100 cc. Cork tightly and let stand 24 hours. Pipette off 10 cc. of the clear supernatant liquid, make up to 50 cc., Nesslerize, and read after ten minutes. The reading obtained, multiplied by ten, gives the nitrogen expressed as parts per million.

CONCLUSION. Direct Nesslerization saves much time and gives results quite as satisfactory as the standard steam distillation

method. If there were any elements present that might have produced turbidity, they were automatically removed. The distinctive features of this method, as compared with that of Whipple's, are that instead of Nesslerizing directly, the alkaline solution is allowed to stand for a period of 24 hours before adding the Nessler's reagent. The results determined without this period are not uniform, but are low for a shorter period and also for a 48-hour period. The 24-hour period, however, gives very satisfactory results. The other feature is that the sample is pipetted off as a supernatant liquid, and not filtered. This method is the result of a year's experimentation, during which time between 300 and 400 determinations were made. The method has proved satisfactory and has been used in the Water and Sewage Laboratory of the Kansas State Board of Health for the past year.

FREE AMMONIA.

Free ammonia is an intermediate product in the nitrogen cycle, and is the first step in the mineralization of the nitrogenous matter present. As it is a decomposition product, the quantity present is a valuable indication of the freshness of the sewage. Free ammonia does not of itself constitute a source of offensive odor, and it does not ordinarily represent organic matter which will decompose and cause offensive conditions. An excessively high amount of free ammonia in an effluent, however, indicates little oxidation and an objectionable effluent. The determination of free ammonia by the distillation method is somewhat inaccurate, because some unstable substances, as urea, give off their nitrogen on heating to the extent required for the distillation, and high results are obtained. Free ammonia was determined by direct Nesslerization in this laboratory, and as the results were found reliable, this method was preferred.

PROCEDURE. Place 50 cc. of the sample in a 100 cc. Nessler tube, add a few drops of a 10 percent solution of copper sulphate and 1 cc. of a 50 percent solution of sodium hydroxide, and mix thoroughly. Cork the tube tightly and allow it to stand for 24 hours. A heavy precipitate falls to the bottom and leaves a clear supernatant liquid. Pipette off 10 cc., make up to 50 cc., and Nesslerize. Multiply the reading by two to obtain parts per million.

NITRITES AND NITRATES.

The oxidation of ammonium compounds into nitrites and finally into nitrates, or nitrification, is the last step in the complete biological purification of sewage. The determination of nitrogen in the form of nitrites and nitrates is, therefore, instructive as regards the efficiency of the plant operations.

PROCEDURE. *Nitrites.*—Measure out into a Nessler tube 50 cc. of sewage, or less if the strength of the sewage warrants, add 2 cc. each of sulphanilic acid and a-amido-naphthalene solutions. Let stand for ten minutes and compare against standards. Using a 50 cc. sample, the reading gives the parts per million direct.

Nitrates.—The chlorine content of most Kansas sewages is not high enough to interfere with the phenolsulphonic-acid method, which is as follows:

Evaporate 10 cc. of the sample in a small evaporating dish, removing it just before it has come to dryness. Add 1 cc. of phenolsulphonic acid and mix with the residue. Let stand for a short time. Rinse into a 100 cc. Nessler tube and make alkaline with 10 cc. of a 50 percent solution of sodium hydroxide. Make up to 100 cc. and compare with standard. Multiply the reading by 0.10 to obtain parts per million of nitrogen as nitrates.

DETERMINATION OF DISSOLVED OXYGEN.

MODIFIED WINKLER METHOD.

Reagents.

(1) Sulphuric acid, concentrated (sp. gr., 1.83-1.84).
(2) Potassium permanganate (6.32 gms. per liter).
(3) Potassium oxalate (2 percent solution).
(4) Manganous sulphate (480 gms. per liter).
(5) Alkaline potassium iodide (700 gms. KOH and 150 gms. potassium iodide per liter).
(6) Hydrochloric acid, concentrated (sp. gr., 1.18-1.19).
(7) N-40 sodium thiosulphate.
(8) Starch solution.

COLLECTION OF SAMPLES. Collect the sample in a narrow-necked glass-stoppered bottle of from 250 to 270 cc. capacity. Exercise extreme care to avoid the entrainment or absorption of atmospheric oxygen.

In collecting from a tap, fill the bottle through a glass or rubber tube extending well into the tap and extending to the bottom of the bottle, so as to avoid air bubbles. Allow the bottle to overflow

for several minutes, after which carefully replace the glass stopper so that no air bubble is entrained.

In collecting from the surface of a pond or tank, use a bottle of one-liter capacity in addition to the sample bottle. Provide each bottle with a two-holed rubber stopper having a glass tube extending to the bottom, and a short glass tube entering but not projecting into the bottle. Connect the short tube of the sample bottle with the long tube of the liter bottle. Immerse the sample bottle in the water and apply suction.

To collect a sample at any depth arrange the two bottles so that the outlet tube of the liter bottle is at a higher elevation than the inlet tube of the sample bottle. Lower the two bottles to the desired depth in a convenient form of cage, properly weighted. Water entering during the descent will be flushed through into the liter bottle. Finally replace the perforated stopper of the sample bottle with a glass stopper, avoiding entrained bubbles of air.

PROCEDURE. Remove the stopper from the bottle and add, under the surface of the water, 0.7 cc. of the concentrated sulfuric acid, and then 1 cc. of the potassium permanganate solution. Insert the stopper and mix by inverting the bottle several times. After 20 minutes have elapsed, destroy the excess of permanganate by adding 1 cc. of the potassium oxalate solution, the bottle being at once restoppered and its contents mixed. In case 1 cc. of the potassium permanganate solution does not leave a noticeable color at the end of twenty minures, add 1 cc. more of the potassium permanganate solution. If this is still insufficient, use a stronger potassium permanganate solution. After the addition of the potassium oxalate and after the liquid has again become colorless, add 1 cc. of the manganous sulphate solution and 3 cc. of the alkaline potassium iodide solution. Allow the precipitate to settle. Add 2 cc. of the hydrochloroic acid and mix by shaking.

Introduce all of the reagents under the surface of the water.

Up to this point carry on the procedure in the field, but after the acid has been added and the stopper replaced there is no further change and the remainder of the operation may be conducted within a few hours, as convenient. Pipette 200 cc. of the bottle contents into a flask and titrate with N-40 solution of sodium thiosulphate, using a few cc. of the starch solution as indicator toward the end of the titration. Do not add the starch solution until the color has become a faint yellow, and titrate until the blue color disappears.

The use of potassium permanganate is made necessary by high nitrite or organic matter content.

The procedure outlined must be followed in all work on sewage and partially purified effluents, and on seriously polluted streams. It is also necessary in any case where the nitrite nitrogen exceeds 0.1 part per million. In all other cases the procedure may be shortened by beginning with the addition of the manganous sulphate solution and proceeding from that point as outlined.

TABLE SHOWING SOLUBILITY OF ATMOSPHERIC OXYGEN AT DIFFERENT TEMPERATURES.

Temp. F.	Temp. C.	Dissolved. oxygen.	Temp. F.	Temp. C.	Dissolved oxygen.	Temp. F.	Temp. C.	Dissolved oxygen.	Temp. F.	Temp. C.	Dissolved. oxygen.
32.0	0.0	14.62	47.3	8.5	11.73	62.6	17.0	9.74	77.9	25.5	8.30
32.9	0.5	14.42	48.2	9.0	11.59	63.5	17.5	9.64	78.8	26.0	8.22
33.8	1.0	14.23	49.1	9.5	11.46	64.4	18.0	9.54	79.7	26.5	8.14
34.7	1.5	14.04	50.0	10.0	11.33	65.3	18.5	9.45	80.6	27.0	8.07
35.6	2.0	13.84	50.9	10.5	11.20	66.2	19.0	9.35	81.5	27.5	7.99
36.5	2.5	13.66	51.8	11.0	11.08	67.1	19.5	9.26	82.4	28.0	7.92
37.4	3.0	13.48	52.7	11.5	10.95	68.0	20.0	9.17	83.3	28.5	7.84
38.3	3.5	13.30	53.6	12.0	10.83	68.9	20.5	9.08	84.2	29.0	7.77
39.2	4.0	13.13	54.5	12.5	10.71	69.8	21.0	8.99	85.1	29.5	7.70
40.1	4.5	12.96	55.4	13.0	10.60	70.7	21.5	8.91	86.0	30.0	7.63
41.0	5.0	12.80	56.3	15.5	10.48	71.6	22.0	8.83	......	......	......
41.9	5.5	12.64	57.2	14.0	10.37	72.5	22.5	8.75	......	......	......
42.8	6.0	12.48	58.1	14.5	10.26	73.4	23.0	8.68	......	......	......
43.7	6.5	12.32	59.0	15.0	10.15	74.3	23.5	8.60	......	......	......
44.6	7.0	12.17	59.9	15.5	10.05	75.2	24.0	8.53	......	......	......
45.5	7.5	12.02	60.8	16.0	9.95	76.1	24.5	8.45	......	......	......
46.4	8.0	11.87	61.7	16.5	9.85	77.0	25.0	8.38	......	......	......

NOTE.—Dissolved oxygen expressed as parts per million.

OXYGEN CONSUMED.

Determinations of nitrogen do not give any information as to the quantity of organic matter in which nitrogen is absent. As a measure of the carbonaceous as well as of the nitrogenous organic matter, the "oxygen consumed," "oxygen absorbed" or "oxygen required" determination is used. The results of the oxygen consumed determination are not ordinarily reported as to give an idea of the weight of the organic matter in a given volume of sewage or effluent, but rather to obtain the quantity of oxygen required for its chemical combustion. It is, then, only of a relative value, furnishing a means of comparison. In other words, the "oxygen consumed value" is only a comparative, indirect indicator of the concentration of the sewage with respect to organic matter.

Reagents.

(1) Dilute sulphuric acid. One part of acid to three parts of distilled water.
(2) Standard potassium permanganate solution. Dissolve 0.4 gram of the crystallized chemical in 1 liter of distilled water. Standardize against an ammonium oxalate solution. One cc. is equivalent to 0.1 mg. of oxygen.
(3) Ammonium oxalate solution. Dissolve 0.888 grams of the substance in 1 liter of water. One cc. is equivalent to 0.1 mg. of oxygen.

PROCEDURE. Measure out 5, 10 and 20 cc. of the sample as the strength of the sewage requires, add 10 cc. of the sulphuric acid solution and 10 cc. of the potassium permanganate solution. Heat to boiling and keep boiling exactly five minutes. Keep the solution colored by adding more potassium permanganate if necessary. Discharge the pink color with ammonium oxalate solution; titrate with the potassium permanganate solution until a faint but distinct color is obtained. A blank determination should in all cases be carried out under the exact conditions of the actual determination, except that distilled water should be used. The standardization of the permanganate against the oxalate gives the true strength of the former. The blank test gives the relative strength of the two solutions under the conditions of the test—a value usually different from the standardization value. The amount of permanganate used in the determination, minus the blank, is the amount actually consumed by the organic matter. This value, times 100, divided by the number of cc. of sample taken, gives the result in parts per million of oxygen.

RELATIVE STABILITY.

If the organic matter of an effluent has been transformed to such a form that it is incapable of offensive putrefaction, the effluent is said to be stable. Or, if it has sufficient dissolved oxygen and oxidized products present to decompose the organic matter under aërobic conditions—*i. e.*, the available oxygen exceeds the required oxygen—it is stable. A perfectly stable effluent has a relative stability of 100. If the available oxygen is 75 percent of the required oxygen, the effluent has a relative stability figure of 75. In determining the relative stability, advantage is taken of the fact that a sewage to which a little methylene blue has been added retains its blue color if there is any available oxygen present, but becomes colorless in the absence of available oxygen.

PROCEDURE. Take sample in a 150 cc. bottle and add 1 cc. of a 2 percent solution of methylene blue. Take care not to include

any bubbles of air in corking. Incubate at 20° C. or 37° C. until the color is discharged. Calculate the relative stability from the following table:

RELATIVE STABILITY NUMBERS.

t^{20}	t^{37}	S	t^{20}	t^{37}	S
0.5	...	11	8.0	4.0	84
1.0	0.5	21	9.0	4.5	87
1.5	...	30	10.0	5.0	90
2.0	1.0	37	11.0	5.5	92
2.5	...	44	12.0	6.0	94
3.0	1.5	50	13.0	6.5	95
4.0	2.0	60	14.0	7.0	96
5.0	2.5	68	16.0	8.0	97
6.0	3.0	75	18.0	9.0	98
7.0	3.5	80	20.0	10.0	99

S = Relative stability or ratio of available oxygen required for equilibrium. Expressed in percents.

t^{20} = Time in days to decolorize methylene blue at 20° C.

t^{37} = Time to decolorize at 37° C.

Theoretical relation: $S = 100\ (1 = 0.794\ t^{20})$; $S = 100\ (1\text{–}620\ t^{37})$.

In general effluents having a relative stability greater than 90 may be discharged into any stream without danger of their consuming any of the oxygen of the water, because effluents of such high stability will retain oxygen indefinitely on exposure to air.

For sewages and effluents which have a very low relative stability this test may be employed to determine the actual strength of the putrescible material present. For this purpose dilutions with fully aërated tap water was made. The amount of dilution will depend on the strength of the sewage, and will probably range from 1 part of sewage to 3 parts of water to 1 to 10. A stability of 100 would indicate that at the dilution used in a fairly good stream, putrefaction would not take place. A relative stability of 50 would indicate twice the volume of diluting water employed in the test would be necessary in the stream in order to render the mixture stable.

BIOCHEMICAL OXYGEN DEMAND.

This test has the same basis as the relative stability, but while the relative stability test is only comparative, the oxygen demand test attempts actually to ascertain the amount of oxygen necessary to obtain a stable effluent. It is made under conditions closely approximating those existing in the receiving watercourse, and

so affords valuable data regarding the danger of pollution. The method is based on the biochemical consumption of available oxygen in sodium nitrate by a sewage during an incubation period of 10 days at 20° C. The amount of available oxygen added as nitrate, minus the final amount as determined, indicates the amount that has been used up in keeping the sewage stable. This figure divided by four (the number of parts per million of oxygen that can be furnished by a stream without danger of pollution) gives the size of the stream required to dilute the sewage or effluent. For example, if 200 parts per million of oxygen are added, and at the end of 10 days 100 parts per million are found, the biochemical oxygen demand is 100 parts per million. A stream 25 times the volume of the sewage to be added is necessary for its dilution.

PROCEDURE. Fill a 250 cc. bottle with sample, add 2 cc. of sodium nitrate solution (25.56 gms. per liter, 1 cc. of which in 250 cc. of water represents 50 parts per million of available oxygen), and 1 cc. of a 2 percent solution of methylene blue. Incubate for 10 days at 20° C., adding sodium nitrate from time to time if necessary to retain the blue color. At the end of 10 days determine the amount of nitrites and nitrates. Multiply the nitrite nitrogen by 1.7 and the nitrate nitrogen by 2.9, in order to convert the nitrogen into terms of available oxygen. The differences between the available oxygen added as sodium nitrate and that found as nitrite and nitrate at the end of the incubation period gives the biochemical oxygen demand in parts per million.

CHLORINE.

The quantity of chlorine per inhabitant that enters the sewers in a given unit of time is more or less uniform, so the chlorine content of a sewage is somewhat of an indication of its strength. It is necessary, however, to know the quantity of chlorine in the water supply, and also any source of an unusually large quantity of chlorine discharged into the sewers. Bearing this factor in mind in the interpretation of the results obtained, a good idea of the strength of the sewage can be obtained. The amount of infiltration into the sewers may be ascertained by the degree of dilution afforded the sewage, the chlorine content of the sewage being known. The chlorine content of most Kansas waters is so high that the added chlorine from the sewage is too small a fraction to give very valuable results. It is a standard method, however, and is of some value even in Kansas sewages.

PROCEDURE. Measure 50 cc. of sample into a porcelain casserole, add 2 drops of potassium chromate indicator (50 gms. per liter) and titrate against a standard silver nitrate solution (2.40 gms. per liter). The number of cubic centimeters of silver nitrate used times 20 gives parts per million of chlorine. A satisfactory end point cannot be obtained when more than 10 cc. of the silver nitrate solution are necessary in the titration.

FATS.

The amount of fats in a sewage is determined generally in connection with projects for its recovery and sale. While the fat in itself is relatively stable, it sometimes clogs the contact beds or sand filters. A sewage which contains a large amount should receive treatment for its removal.

OTHER CHEMICAL TESTS.

Carbon dioxide is formed in the process of mineralization of the carbonaceous organic matter and is sometimes determined. Special conditions often require individual tests. These are so numerous that space will not be given for their discussion.

BACTERIOLOGICAL AND BIOLOGICAL TESTS.

Bacteriological analyses are often made in connection with chemical tests for the purpose of plant control. There are no methods by which the absolute number of bacteria in a sample can be determined, and all quantitative determinations of bacteria are necessarily of a relative character. This being the case, strict adherence to standard methods is absolutely necessary. Probably the most important tests are the total count on standard agar media at 37° C.; the number of red colonies on lactose-litmus agar, and the number of colonies on gelatine at 20° C. If these tests are carried out correctly they give comparatively quantitative results, though they are not absolute. Technique in bacteriological analysis is of prime importance, and the conditions of sampling and analysis should not vary from day to day. "Standard Methods of Water Analysis"* should be consulted for further information regarding technique and methods.

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*Published by The American Public Health Association, 289 Fourth avenue, New York City.

Conclusions.

Few of our Kansas cities are large enough to warrant the maintenance of laboratories necessary for running a complete sewage analysis, and it is seldom that a complete analysis is necessary. However, a plant operator should be able to interpret results of a sewage analysis and to run such tests as may be necessary for the intelligent operation of his particular plant.

CHAPTER VI.

THE OPERATION OF AUTOMATIC APPARATUS FOR CONTROL OF SEWAGE DISPOSAL WORKS.*

IT is of extreme importance, in the successful operation of a sewerage system or of a sewage disposal plant, that the operator have a clear understanding of the construction and operation of the various devices which control the passage of sewage through the mains and disposal plant.

The following described devices are commonly used in Kansas plants.

It was impossible to get cuts and detailed explanations of all the types of apparatus used in the state, but it is thought that the ones given will serve for an exposition of the principles involved, even though the actual layout is somewhat different.

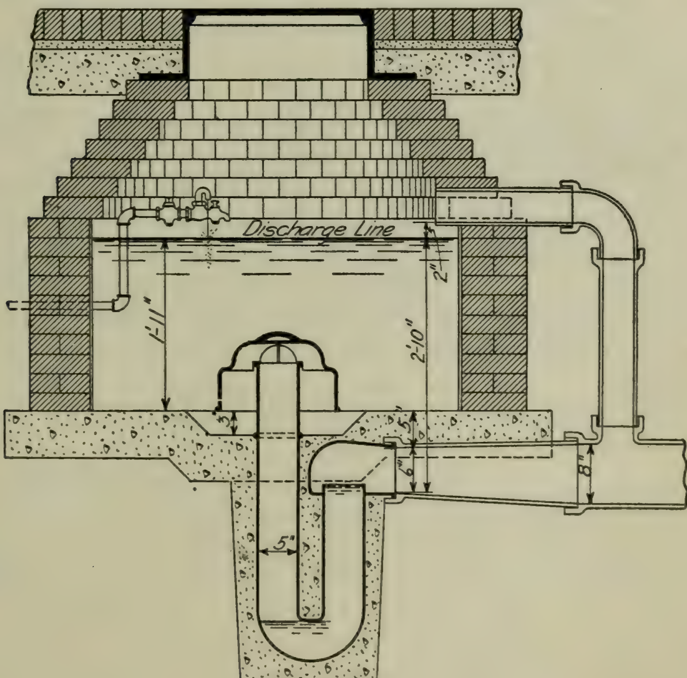

FIG. 12.

*The cuts for the illustration of this chapter were furnished by the Pacific Flush Tank Company, of Chicago, Ill., and the directions for operation is in each case copied from their general Catalogue. The apparatus of this company is in general use in Kansas.

Flush Tanks.

Probably the most important of automatic devices is the flush tank. One of these is located at the head or dead end of every lateral of a well-designed sewer system.

The purpose of a flush tank is to periodically discharge a large amount of water through the sewer in order that its scouring action will be utilized to wash out any obstructions. It is necessary then to have an apparatus which will store water at a constant rate until a sufficient volume is obtained and then discharge it as rapidly as possible, so that its effect will be concentrated.

Figure 12 shows a design of tank for this purpose. The operation of the tank is as follows:

1. After the well is built, the siphons and piping set as is shown in the figure, and before the bell is placed over the long leg of the siphon, water is poured into the siphon until it will hold no more—that is, until water begins to flow through the outlet.

2. The bell is now replaced and the water from the city supply turned on.

3. As the water rises above the sniff hole the air in the bell is compressed and forced down on the water in the siphon. This continues until the water in the long leg has been forced down to the bend of the pipe. The pressure is now in equilibrium, since the height of water in the tank is equal to the length of the column in the short leg of the siphon. Now as more water is added to the tank this equilibrium is destroyed and the extra head of the water in the tank causes it to rise in the bell and start to flow into the long leg. At the same time the compressed air in the siphon is released into the vent pipe, and the contents of the tank is rapidly discharged into the sewage.

When the water in the tank has been drawn down below the bell, a complete circulation of air is obtained, the water in the bell falls back to a level with the lower edge of the bell and the water in the siphon is drawn down until it stands at an equal height in both legs. The tank is now in position for starting again.

The water for operating the tank is obtained from the city supply and is fed through a faucet or through a standard regulator. The former method generally results in a waste of water, however, since the ordinary faucet can not be adjusted to discharge a stream so small as to allow the tank to flush once in twenty-four

hours without a great danger of clogging. It is customary, therefore, to use some form of regulator. This consists of an orifice, drilled in the end of a plug, filled into the U-shaped tube (shown in the figure). This orifice is so designed to admit a certain amount of water under a certain pressure. Therefore by changing its size the period of flushing may be altered at will.

Regulators are generally provided with a cock for rapid flushing.

In the operation of tanks the following points should be watched:

1. Leakage in walls of the tank.
2. Clogging or corrosion of the unit cock or regulator.
3. Accumulation of sediment in the tank. This usually comes from siftings of earth through or around the cover from the roadway above. It is customary to use a dust pan whenever perforated covers are used. Flush tanks should be visited once each month, and the discharge of the feed cock or regulator tested from time to time. A convenient method is to note the time necessary to fill a gallon measure.

Control Apparatus for Sewage Disposal Plants.

Sewage disposal plants which consist only of septic or settling tanks do not, as a rule, employ automatic control apparatus, and although a few of the earlier installations of septic tanks in this state were equipped with siphons which cause the effluent to be discharged intermittently, the present practice is to allow the sewage to flow direct from the tank into the receiving watercourse.

However, when secondary treatment is desired it is customary to use automatic apparatus for regulating the flow of sewage through the plant. There are two types of apparatus in general use, namely:

1. Those which store the sewage in a tank until the required amount for the dosing of one secondary unit is at hand. This type will be called the dosing chamber type.
2. Those which allow the sewage to flow regularly until the secondary unit has been filled and then automatically cut off the flow and divert it into another unit. This type will be called the continuous flow type.

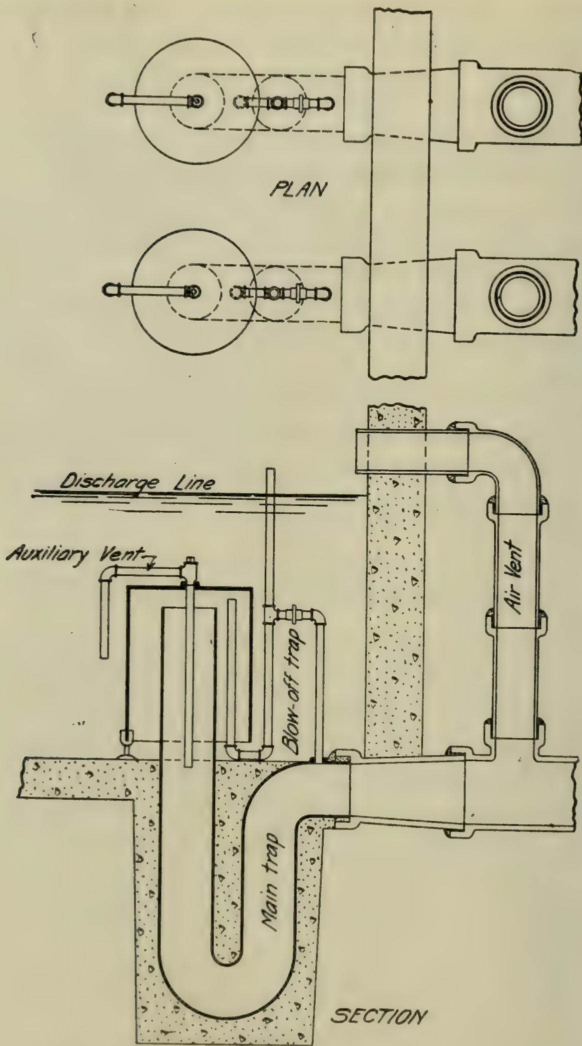

FIG. 13.

Dosing Chamber Types.

1. SINGLE SEWAGE SIPHONS.

These are used when there is but one secondary unit, and the principle of operation is identical with that which applies in the case of the flush tank, and which has been explained above.

2. DOUBLE SEWAGE SIPHONS.

These are used when two secondary units are to be dosed alternately. Figure 13 shows a plan of the two siphons and a section of one of them.

The following terms will be used in the explanation, and reference is made to Figure 14.

Main trap: The large casting set in the concrete, the long leg of which extends above the floor of the dosing tank, and the short leg being connected to the discharge pipe leading to the filter bed.

Bell: The casting which is placed over the long leg of the trap and which is supported by cast-iron legs or masonry piers resting on the floor.

Blow-off trap: Piping which is screwed into the short leg of the main trap, and having one end extend above the discharge line, the other end extending up under the bell.

Auxiliary Vent: Pipe leading from top of bell and having one end extend down into the long leg of the trap, the other end terminating on the outside of the bell.

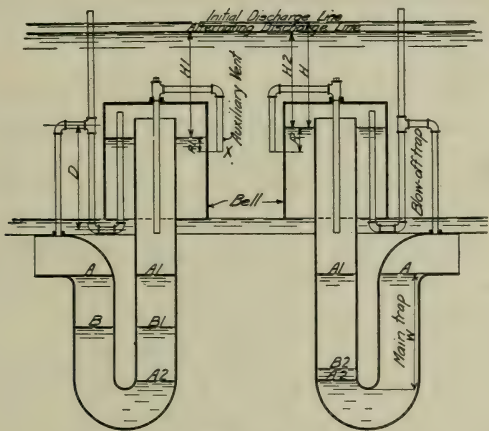

FIG. 14.

TO START APPARATUS. First, fill all main and blow-off traps with water.

OPERATION. The main and blow-off traps of both siphons having been filled, the water levels in the main traps will then be at A and A_1. The tank is then allowed to fill, and when the water level reaches the auxiliary vent pipe at X the air within the siphons is confined and put under a pressure which gradually increases as the water in the tank rises. The pressure forces the water in the long legs of the traps down, and when the maximum depth in the tank is reached, or, in other words, the discharge

line, the levels in the main traps will be at A and A_2. The depression in the traps is accompanied by a rise in the bells above the end of the auxiliary vents, the amount of this rise (R) depending upon the amount of water in the main traps.

It can now be seen that the column of water $A\text{-}A_2$ is held in equilibrium by the column of water represented by the head (H), and as the depth of seal of the blow-off trap (D) is equal to H, this seal will be forced, thus releasing the air confined in the siphon and bringing same into operation. The tank is then emptied down to the bottom of the bell. (It might be stated here that at the first discharge either siphon might operate.) If both were constructed and set perfectly they would both be brought into operation at the same time, but any slight variation in the construction or elevations of setting will be sufficient to bring one into operation in advance of the other. For this explanation we have assumed that siphon No. 2 was the first to operate.

The above explanation applies to the initial discharge only, and the succeeding discharges will take place under somewhat different conditions.

In starting, the main traps of both siphons were full. This is not the case after the first discharge. When the pressure forced the levels A_1 down to A_2 the displaced water runs off in the pipes leading from the discharge end of the traps. As above stated, siphon No. 2 operates, and as it draws the water from the tank the pressure on siphon No. 1 (or idle siphon) is gradually reduced until the lower end (X) of the auxiliary vent is reached, when atmospheric pressure is restored in siphon No. 1. About half of the seal having been forced out the main trap of siphon No. 1, the water levels in this trap will be at B and B_1, whereas siphon No. 2, having just operated, will be left with a full trap.

As stated in the first paragraph, the rise in the bell (R) depends upon the amount of water in the main trap, and half of the water having been forced out of trap No. 1, the rise in the bell of siphon No. 1 will be only about half of that in siphon No. 2. It will now be seen that the discharge line for the siphon with the weak seal is lower than that with the full seal, and as the rise (R) in the latter is greater than R_1 the head (H_2) on siphon No. 2 is less than H_1, the head on siphon No. 1.

Therefore, siphon No. 1 having the greatest head, and the head being equal to D, the seal of the blow-off trap will be forced and siphon No. 1 brought into operation.

On the third filling of the tank the above conditions will be

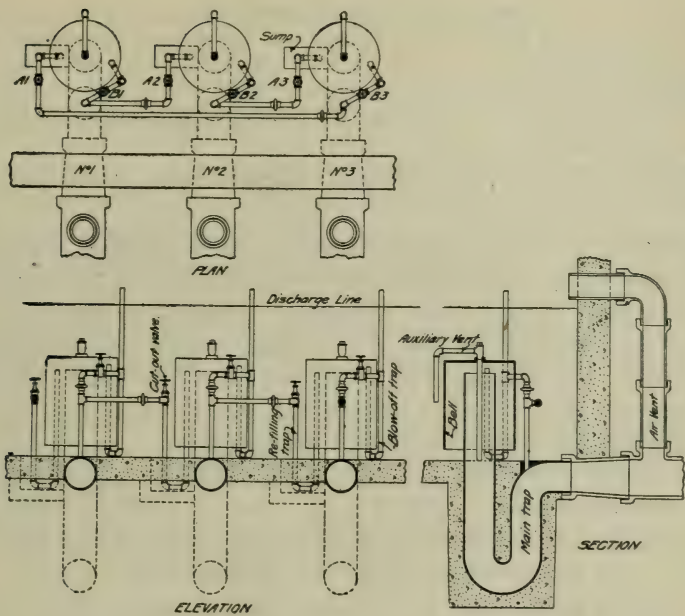

FIG. 15.

reversed, and siphon No. 2 having a weakened seal will again be brought into operation.

Double alternating siphons do not require connecting piping, and if properly set should not get out of order.

3. TRIPLE ALTERNATING SIPHONS.

This type is sometimes used when three secondary units are to be used. This apparatus operates on the same principle as the double alternating siphons. The following description refers to Figure 15:

The following terms will be used in the explanation and reference is made to Figure 15:

Main trap: The large casting set in the concrete, the long leg of which extends above the floor of the dosing tank, and the short leg being connected to the discharge pipe leading to the filter bed.

Bell: The casting which is placed over the long leg of the trap and which is supported by cast-iron legs or masonry piers resting on the floor.

Blow-off trap: Piping which is screwed into the short leg of the main trap, and having one end extending above the discharge line, the other end extending up under the bell.

Refilling trap: Piping having one end connected to the blow-off trap and the other extending up under the bell.

Auxiliary vent: Pipe leading from top of bell and having one end extend down into the long leg of the main trap, the other extending down on the outside of the bell.

TO START APPARATUS. First fill all main, blow-off and refilling traps with water.

Open all valves in blow-off and refilling traps. Then turn supply into tank.

OPERATION. When the discharge line is reached one of the three siphons will be brought into operation by the forcing of the blow-off seal, as described in double alternating siphons. The tank is emptied and the seal of the siphon which has just operated is refilled. The condition now existing after the first discharge is the same as in the double alternating, except that there are two idle siphons with weakened seals instead of one.

Upon the second filling of the tank, either of the two siphons with weakened seals might operate, and to definitely determine which it shall be necessitates the refilling of one of the weakened traps. This is accomplished by the refilling traps.

It will be noted that the refilling trap of siphon No. 1 is connected to the main trap of siphon No. 3, the refilling trap of siphon No. 2 to the main trap of Siphon No. 1, and the refilling trap of siphon No. 3 to the main trap of siphon No. 2. Therefore when siphon No. 1 operates, water flows through its refilling trap and into the main trap of siphon No. 3. Thus at the end of the discharge the main traps of siphons No. 1 and No. 3 are both full, while No. 2 is still weakened, and upon the next filling of the tank will be the one to operate. When No. 2 discharges it refills trap No. 1, leaving No. 3 weak, and when No. 3 discharges it refills trap No. 2, leaving No. 1 with a weakened seal.

This operation is repeated indefinitely.

CUTTING OUT SIPHONS. The valves in the blow-off and refilling traps are for cutting out any one of the siphons, the other two continuing to alternate as before.

When all three siphons are in service all valves should be open.

To cut out a siphon it is necessary to close two valves only. The following table shows which valves are closed to cut out any siphon:

To cut out siphon No. 1 close B1 and A3.
To cut out siphon No. 2 close B2 and A1.
To cut out siphon No. 3 close B3 and A2.

4. PLURAL ALTERNATING SIPHONS.

When the number of secondary units exceeds three it is customary to use plural alternating siphons. In the following description reference is made to Figure 16.

GENERAL. It will be noted in the previous explanation of double and triple alternating siphons that the operation of both types depend upon one of the traps having a weakened seal. This principle might be applied to four or more siphons, but the system of piping for refilling the idle traps would necessarily be complicated, and so in order to avoid this and at the same time make the apparatus simple and easy to install, a different principle is used.

The following terms will be used in the explanation, and reference is made to Figure 16, which shows four Miller plural alternating siphons:

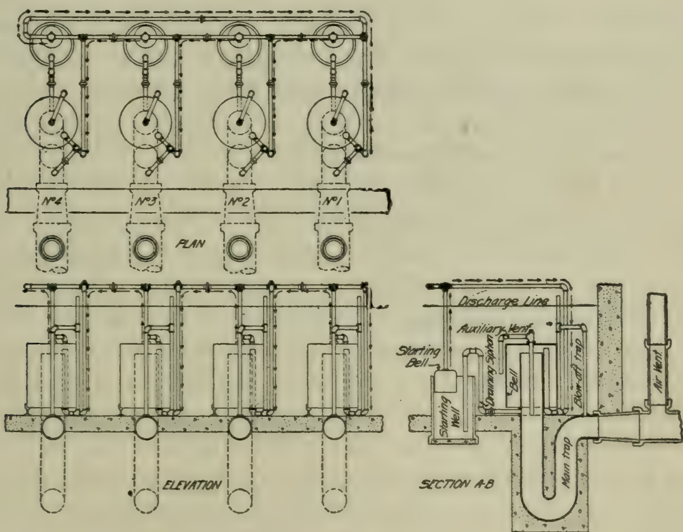

FIG. 16.

Main trap. The large casting set in the concrete, the long leg of which extends above the floor of the dosing tank, and the short leg being connected to the discharge pipe leading to the filters.

Blow-off trap: Piping which is screwed into the short leg of the main trap, and having one end extend above the discharge line in the tank, the other end extending up under the bell.

The blow-off traps are all connected to the loop piping.

Bell: The casting which is placed over the long leg of the trap, and whicb s supported by the castiron legs resting on the floor, or on masonry piers

Auxiliary vent: Pipe which leads from the top of bell, and having one end extend down into the long leg of the main trap, the other coming down on the outside of the bell.

Starting well: Tile set in floor of dosing tank, one back of each siphon.

Starting bell: Small cast-iron bell suspended from the air loop piping, and hanging in the starting well.

Draining siphon: Piping leading from long leg of main trap and extending down into the starting well.

TO START APPARATUS. First fill the tile wells in back of siphons No. 2, No. 3 and No. 4 with water, leaving well No. 1 empty.

Next fill all main traps and blow-off traps with water.

Then turn the three-way air cocks in the loop piping so that the air from each starting bell will be transmitted as shown by the arrows in Figure 26. The square head plugs on the three-way cocks indicate the direction of flow through the three openings.

Then turn the supply into the dosing tank.

OPERATION. The liquid in the tank gradually rises and finally overflows into starting well No. 1 (which it will be remembered was left empty), and the starting bell being filled with air, pressure is developed which is transmitted, as shown by the arrows, to the blow-off trap connected with siphon No. 2. When the discharge line is reached sufficient head is obtained on the starting bell to force the seal in blow-off trap No. 2, thus releasing the air confined in siphon No. 2 and bringing it into full operation.

During the time that siphon No. 2 is operating, siphonic action is developed in the draining siphon connected with starting well No. 2, and as soon as the level in the tank is below the top of the well it is drained down to a point below the bottom of starting bell No. 2. It can now be seen that after the first discharge starting well No. 2 is empty, whereas the other three are full, well No. 1 having been filled when the tank was emptied by siphon No. 2.

Therefore, when the tank is filled the second time, pressure is developed in starting bell No. 2, which forces the seal of blow-off trap No. 3, thus starting siphon No. 3. Siphon No. 3 drains starting well No. 3, and on the third filling of the tank starting bell No. 3 brings siphon No. 4 into operation. This siphon drains well No. 4, and on the fourth filling of the tank, pressure is transmitted back to blow-off trap No. 1, bringing siphon No. 1 into operation.

This cycle is repeated continuously.

Continuous Flow Type.

This type of dosing apparatus is sometimes used on contact beds, and has the advantage of requiring less head for its operation, since the dosing chamber is eliminated.

Reference is made to Figure 17 in the following description.

GENERAL. The Miller-Adams air-lock feed is an apparatus for filling contact beds, and as a general rule its use is adopted on account of the small amount of fall required for its installation. The construction and principles of operation are entirely different from those of alternating siphons.

The following terms will be used in the explanation, and reference is made to Figure 17:

Feed: Casting which straddles wall in front of outlet from distributing channel to contact bed.

Compression dome: Bell-shaped casting resting on piers in the compression chamber, and having a pipe connecting the center of the dome with the top of the inlet end of the feed.

Starting bell: Small casting suspended in the compression chamber and being connected with the air loop piping.

Blow-off trap: Piping located in the compression chamber, and having one end connected with the top of the outlet end of the feed, the other being connected to the loop piping.

Withdrawing siphon: Pipe siphon passing through the wall of the compression chamber, and having one end extend into the contact bed, the other end coming down in the compression chamber to a point below the bottom edge of the compression dome.

Compression chamber: Concrete chamber containing dome, starting bell, blow-off trap, and withdraw siphon.

TO START APPARATUS. First, fill with water the wells in front of the feeds, except that feed which is to operate. Then fill all the blow-off traps with water.

Turn the three-way cocks in the air-loop piping so that pressure is transmitted from the starting bell to the blow-off trap of the succeeding feed, and at the same time shuts off the air passage to the preceding feed.

The notches on the square head plugs of the three-way cocks indicate the direction of flow through the three openings.

OPERATION. The sewage flows from the settling tank into the distribution channel, and from there through the feed into the bed, either on the top or bottom as desired.

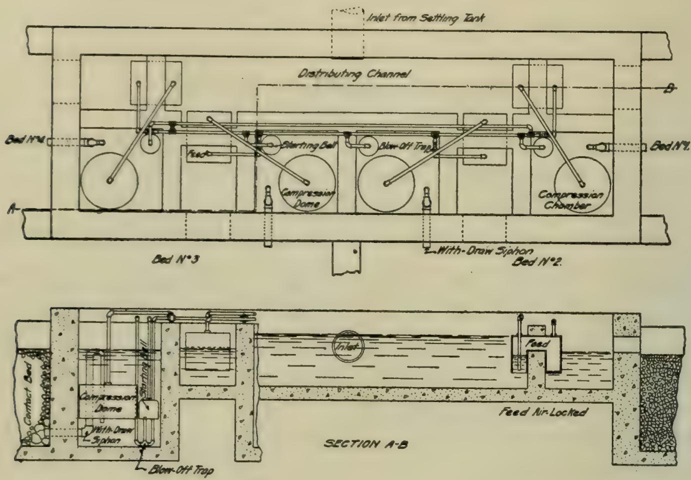

FIG. 17.

This continues until the bed is filled, or when the sewage level in the bed reaches the top of the withdrawing siphon. This point being reached, the withdrawing siphon is brought into operation and the compression chamber filled to the level of the sewage in the contact bed.

As the compression chamber fills, the air in the compression dome is put under pressure and forced into the feed which is running, through the pipe connecting the two. This air lodges in the upper part of the feed and gradually forces the flowing sewage down below the inside crest of the feed and air-locking it, the levels being as shown in Figure 27.

The same rise in the compression chamber also produces a pressure in the starting bell, this bell being connected to the blow-off trap of the feed next to operate. When the head in the compression chamber is sufficient the seal of the blow-off trap is forced, thus releasing the air confined in the feed to which it is connected and allowing the sewage to flow out into the bed. The apparatus is designed so that the next feed is opened before the one that is operating is air-locked, thus preventing any backing up in the distributing chamber.

Each bed upon being filled is allowed to stand in contact for a predetermined time and then discharged by a Miller timed siphon.

The emptying of the contact bed starts siphonic action in the withdrawing siphon, and drains the compression chamber in the same manner that previously filled it. Thus the compression

dome and starting bell are vented, the blow-off trap is refilled, and the chamber is ready for the next filling of the bed.

CUTTING OUT FEEDS. In cutting out of service any one feed it is necessary to turn but two of the three-way air cocks. If feed No. 3 is to be cut out the pressure from starting bell No. 2, which ordinarily would start feed No. 3, must be transmitted to feed No. 4. This is done by turning the three-way which connects blow-off trap No. 3 with the air-loop piping, so that the air passage is along the line of the air-loop piping and blocking off blow-off trap No. 3. Likewise the three-way connecting starting bell No. 3 to the air-loop piping should be turned so that the air passage is along the line of the air-loop piping, and blocks off starting bell No. 3. This gives a direct connection between starting bell No. 2 and the blow-off trap of feed No. 4, thus cutting out feed No. 3.

Operation of Miller Timed Siphons.

GENERAL. The following terms will be used in the explanation, and reference is made to Figure 18:

Main trap: The large casting set in the concrete, the long leg which extends above the floor of the main siphon chamber, the short leg being connected to the discharge pipe from the contact bed.

Blow-off trap: Pipe which is screwed into the short leg of the main trap, and having one end extend above the water line in the chamber, the other end extending up under the bell.

Bell: The casting which is placed over the long leg of the main trap and which is supported by castiron legs or masonry piers.

Harding vent: Piping attached to the side of the bell.

Starting bell: Small castiron bell suspended in the timing chamber by piping leading to the blow-off trap.

Draining Siphon: Piping leading from the long leg of the main trap passing through the wall between the main siphon chamber and timing chamber, and extending down into the tile well located in the latter.

Timing valve: Valve on pipe connecting main siphon chamber and timing chamber.

Main Siphon chamber: Chamber in which the main siphon is located and having an opening at the bottom into the contact bed.

Timing chamber: Chamber containing starting bell, draining siphon and timing valve.

TO START APPARATUS. First, fill the main trap, blow-off trap, and tile well in the timing chamber with water. Do not fill the Harding vent. The contact bed may now be filled.

The size of opening in the timing valve, required to fill the timing chamber in a certain period, will have to be determined by trial.

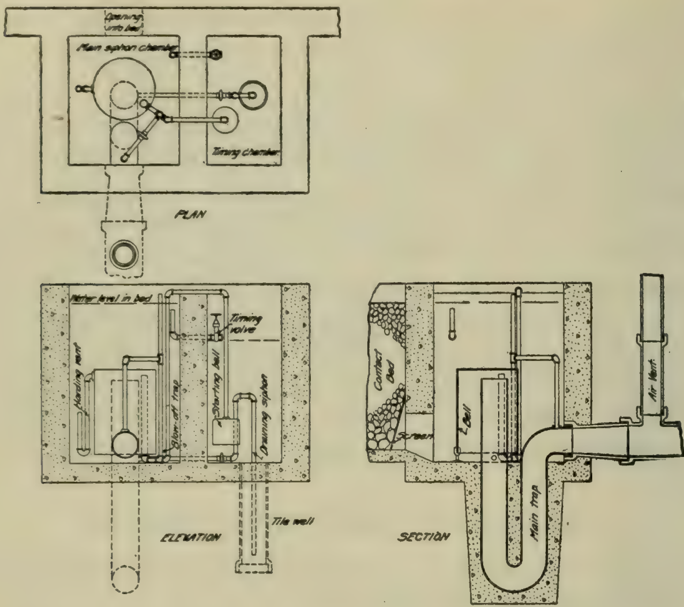

FIG. 18.

OPERATION. Timed siphons are so designed that they cannot be brought into operation until the seal of the blow-off trap is forced by the pressure developed in the starting bell, and as this bell is located in the timing chamber, the main siphon will not start until this chamber is filled to the required depth.

It will be noticed that the timing valve is placed below the high-water line in the contact bed, and therefore when the bed is full there will be a flow from the main siphon chamber into the timing chamber. The time required to fill the timing chamber to the proper depth is regulated by the timing valve, and when this depth is reached the seal of the blow-off trap is forced, thus releasing the air confined in the main siphon, and bringing same into operation. The bed is drained and the siphon vented through the Harding vent.

During the time that the main siphon is operating, the draining siphon is emptying the timing chamber. This vents the starting bell and prepares the timing chamber for the next filling of the contact bed.

The following points should be noted in the operation of all siphons:

1. All joints should be absolutely air tight.

2. Solid matter should not be allowed to accumulate in the bottom of the sump to such an extent that it prevents free access of air into the well when the tank has been emptied.

3. The pipes should be free from obstruction.

In nearly every case when the siphons fail to flush it is merely necessary to lift the bells, allow the tank to drain to the level of the main trap, and replace the bells.

If the siphons do not operate after this has been done examine the apparatus for leaks or clogging.

It is a great convenience to have outlet valves in the chambers of the dosing and timing devices in order that the sewage may be let out to allow for inspection and repairs.

CHAPTER VII.

DISCUSSION OF RESULTS OF TESTS ON CERTAIN SEWAGE DISPOSAL PLANTS IN KANSAS.

THE results of actual tests on sewage disposal plants will be discussed here with the idea of showing how the different operating conditions affect the efficiency of the treatment. It is hoped that the greater number of conditions which affect plant operation have been encountered at some one of the plants tested and discussed herein, and that the plant operator who wishes advice on some point can find the parallel to his trouble in this discussion.

Burlingame.

The sewage disposal plant at Burlingame was constructed in 1913, immediately after the completion of a sanitary sewer system and a waterworks plant; hence this plant has had a special problem to face, that of handling the sewage from a system that is continually receiving more connections and consequently has a continually varying discharge. The plant was designed to treat the sewage flow from the completed system, but at the present time this has been reached only at times when the flow has been increased by storm-water seepage. (See Figure 19.)

The effluent from the plant is discharged into Switzler creek, an intermittent stream tributary to Dragoon creek and the Marais des Cygnes river, and the prevention of pollution of these streams was the object of its installation. The following is a brief tabulated description of the plant. (Line drawings are shown in Plates A and A_1.)

Plant owned by City of Burlingame. Consists of Imhoff tank, contact beds and sludge bed. Built 1913. Treats sewage from city of Burlingame. Population 1910, 1,422; sewer connections in use, 125; persons contributing, 625; condition of system, good.

Rate. Capacity per day: Wet, 138 gallons; average, 56 gallons; dry, 24 gallons per capita per day.

Sewage flow. Average season, 35,400 gallons per day; wet, season, 86,000 gallons per day; dry, season, 14,925 gallons per day.

Source of excess flow. Excess seepage.

Settling compartment. Length, 20 feet; width, 14 feet; depth, 5.5 feet;

capacity, 9,750 gallons. Detention period: Average, 6.6 hours; wet, 2.7 hours; dry, 15.6 hours.

Sludge chamber. Length, 20 feet; width, 19 feet; depth, 9 feet; capacity, 26,250 gallons.

Dosing apparatus. Type, alternating; size, 10 inches; number units, 2 (four planned).

Dosing chamber. Length, 7 feet; width, 7 feet; effluent depth, 36 inches; capacity, 12,000 gallons.

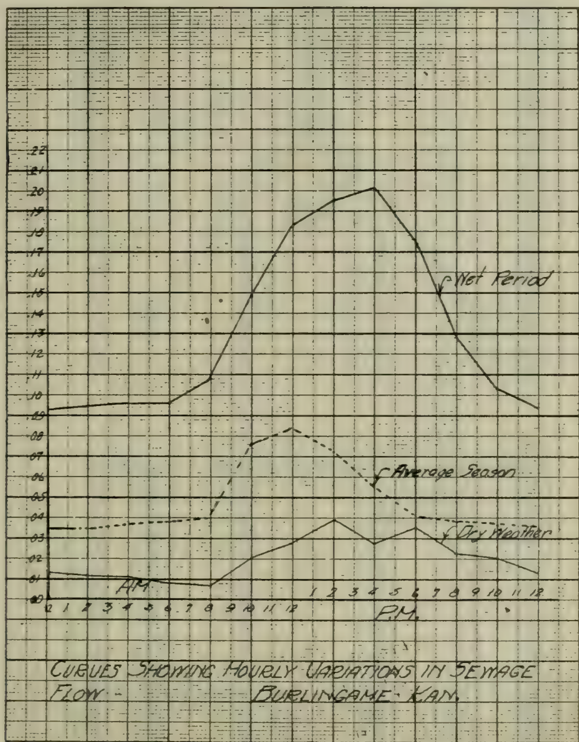

Fig. 19.

Contact beds. Number, 2; filling materials, broken limestone; size of limestone, 1 to 2 inches. Unit No. 1: Length, 68.3 feet; width, 18.5 feet; depth, 4 feet; cubic, gross, 5,050 cubic feet; area, 1,263 square feet; acres, .029. Unit No. 2: Same as unit No. 1.

Operation cycle. Units Nos. 1 and 2. Average season: Fill, 30 minutes; empty, 30 minutes; contact, 45 minutes; rest, 7 hours 15 minutes; rate, 35,400 gallons per day; treatment, 610,000 gallons per acre per day.

Timing apparatus. Type, timing chamber; size, 10 inches; make, Priestman; units, 2.

Distributing syatem. V. S. P.; size, 8 inches; number of openings, 38.

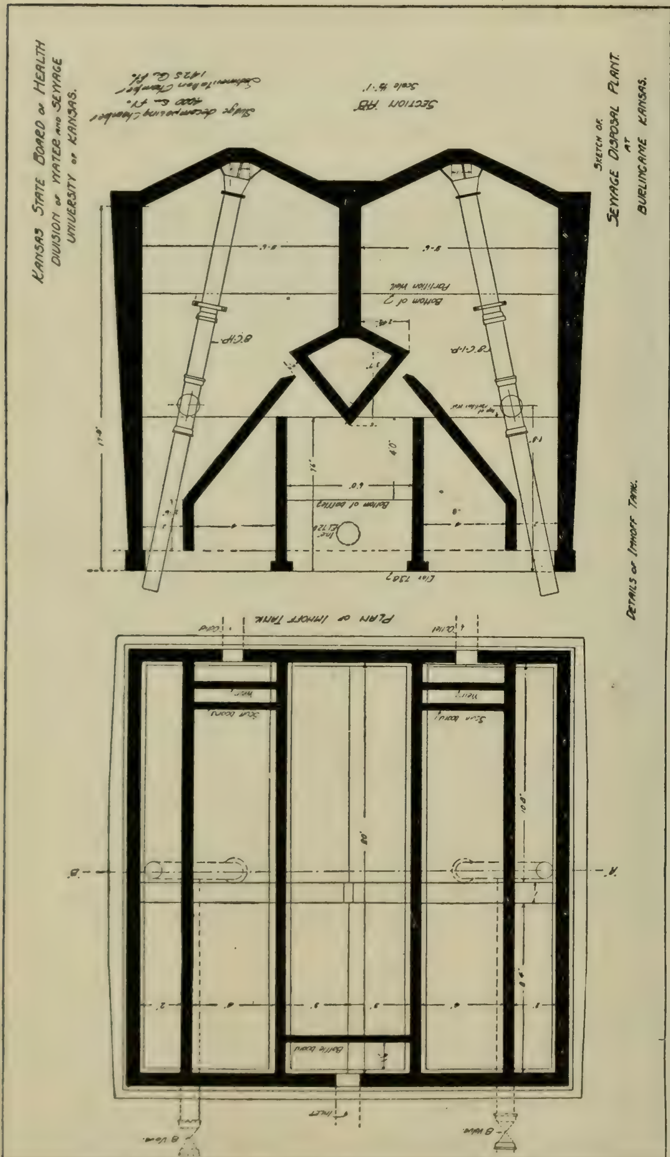

PLATE A.

Construction of Imhoff tank at Burlingame, Kan.

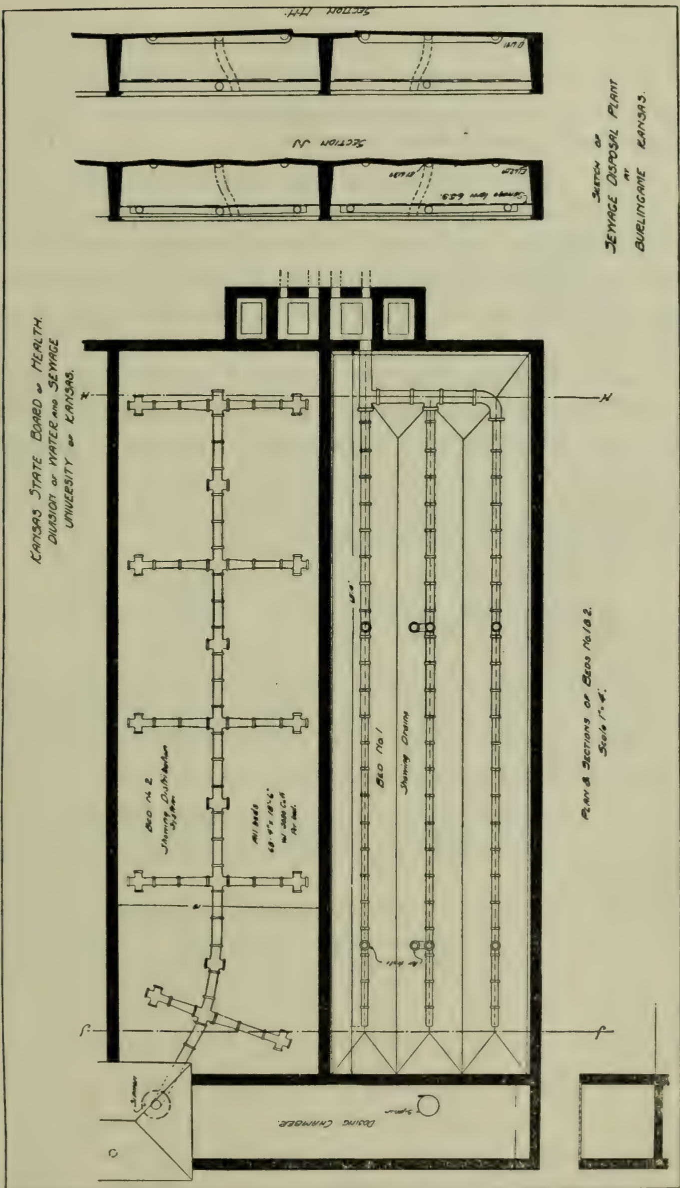

PLATE A$_1$.

Construction of dosing chamber and contact beds at Burlingame, Kan.

Collecting system. V. S. P.; size, 6 inches; number laterals, 3; spaced, 5 feet, center to center.

Main collector. 8 inches.

Sludge bed. Number, 1; construction, 6 inches of sand on 1 foot of rock; length, 30 feet; width, 20 feet; area, 600 square feet; drains, size, 6 inches.

Flood protection. Levee, flap valve on outlet, not curbed.

Sludge handled by gravity from Imhoff tank.

OPERATION. Since there is but one unit in the Imhoff tank and the size of the dosing chamber is unchangeable, the operation of this plant depends largely on the flow of sewage received. The tests were made, however, at three periods when, owing to weather conditions, the flow varied widely, and therefore the operation of the plant under varying sewage flows could be studied. It must be remembered, though, that the increased sewage flow was not normal, that is, due to an increased amount of sewage of normal strength, as would be the case if the number of users of the sewers was increased, but was due to excess water, and hence the sewage at these periods was diluted with fresh water. This is shown very plainly by the dissolved oxygen results, which are:

Dry season average	2.7 p. p. m.
Average season average	4.5 p. p. m.
Wet season average	7.0 p. p. m.

And by the oxygen demand tests, which show that while the sewage requires fifteen times its own volume of water for stability in dry weather, it requires only six volumes during the average season and is stable during the extremely wet season.

IMHOFF TANK. (See Plate A.) The following table shows the percent of suspended solids and "oxygen consumed" removed by the Imhoff tank:

	Percent suspended solids removed.	Detention period, hours.	Percent oxygen consumed, removed.
Dry season	38	15.6	2
Average season	61	6.6	62
Wet season	76	2.7	None.

This shows that for removal of suspended solids the shorter the period the better, and this is true to a great extent for the removal of "oxygen consumed," as is shown by the 62 percent removal with the 6.6-hour period. The "oxygen consumed" result for the 2.7-hour period is explained by the fact that the organic matter was largely in solution and that the gases from the digestion chamber were passing through the flowing sewage. If the gas vents had been free from sludge and scum the results

would probably have shown a larger percent of removal. During the dry season the Imhoff tank effluent was devoid of dissolved oxygen and had a stability figure of 0, which shows that it was in a septic condition, thus defeating the object of this type of tank, which was that of removing the solids from the liquid without absorbing the products of decomposition of sludge. The advantage of the shorter periods is shown by the fact that during the average period the effluent had a stability figure of 21 and traces of dissolved oxygen, and during the wet period it was stable and had six parts per million of dissolved oxygen. It is probable that if the increased flow had been of normal strength the results would not have been so marked, but the only conclusion to be arrived at from these tests is that the shorter the detention period the better.

CONTACT BEDS. (See Plate A_1) The operation of the contact beds during the three periods of test is shown in the following table:

SEASON.	Treatment, gallons per acre per day.	Percent removal of suspended solids.	Percent removal of oxygen consumed.	Detention period in dosing chamber, hours.	Oxygen demand.		Nitrites.		Nitrates.	
					Contact bed.	Imhoff tank.	Contact bed.	Imhoff tank.	Contact bed.	Imhoff tank.
Dry	257,000	32	44	19.2	80	105	......	......	......	......
Average	610,000	7.5	52	8.1	45	72	.13	.36	2.6	.24
Wet	1,480,000	None.	None.	3.3	Stable.	Stable.	......	......	......	......

These results show that although a larger percent of solids and oxygen consumed were removed at the rate of 257,000 gallons per acre per day, the effluent was not as good as that produced with a rate of 610,000 gallons per acre per day. This is probably due to the fact that the sewage was not held so long in the dosing chamber and did not have a chance to become septic before being sent to the contact beds. The wet-weather figures for the contact beds are of little value, as the beds were obliged to be cut out from time to time on account of backwater from Switzler creek.

SEASON.	Percent removal suspended solids.	Percent removal oxygen consumed.	Oxygen demand.			Stability figure contact bed effluent.
			Raw sewage.	Imhoff tank effluent.	Contact bed effluent.	
Dry	58	46	120	105	80	0
Average	64	74	0	72	45	92
Wet	65	None.	50	0	0	99

The above table shows the efficiency of the plant as a whole

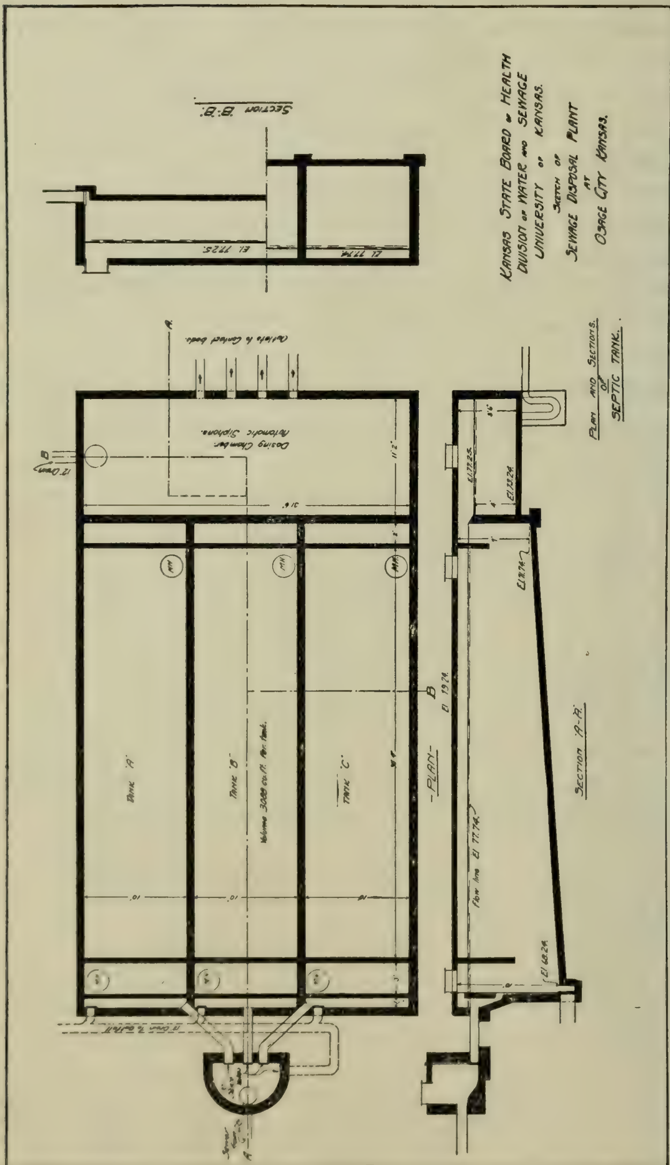

Plate B.

Showing construction of septic tank at Osage City, Kan.

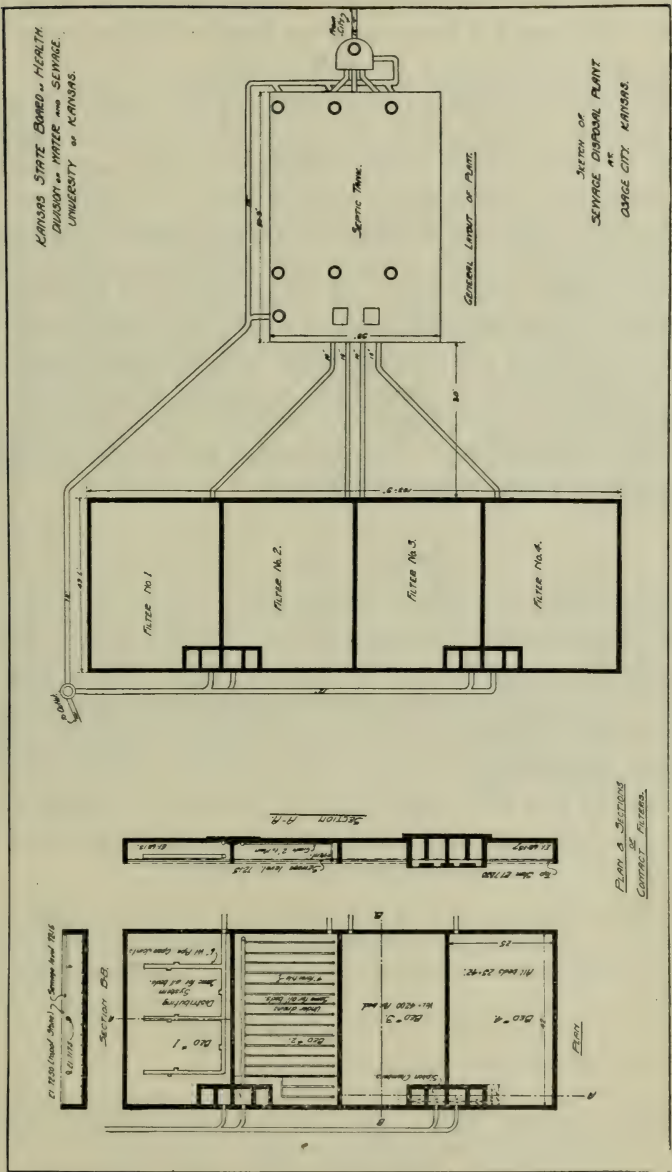

PLATE B_1.

Showing construction of contact beds and the general layout of the Sewage Disposal Plant at Osage City, Kan.

during the different periods, and all things being considered, the best results were obtained during the average period, or when the detention period was 6.6 hours and the rate of treatment on the contact beds 610,000 gallons per acre per day.

There are several points in the operation of this plant that need special attention. There is no automatic device for by-passing the sewage at times of high water, and since the flap valve on the effluent line is only operative so long as there is a higher water level in the creek than in the contact beds, the operator must take care to change the valves so as to by-pass the plant at such times to prevent overflow of the beds and other damage of high water. The normal level of Switzler creek is a very little lower than the level of the outfall of the contact beds, and this creek must be watched closely and the contact beds by-passed when the water level in the creek is high enough to break the seals in the timed siphons of the contact beds. The plant requires careful watching but is capable of giving excellent results.

Osage City.

The sewage disposal plant in Osage City, Kan., was built in 1910 with the intention of preventing the pollution of Salt creek, which is used as a water supply by Lyndon, Kan. The outfall of the Osage City sewer system is but twelve miles above the Lyndon waterworks, and the necessity of careful operation of the Osage City plant is self-evident.

The following is a brief description of the plant at Osage City and of the conditions under which it operates, and Plates B and B_1 show the details of the construction of the plant:

Plant at Osage City, Kan. Owned by Osage City. Consists of septic tank and contact beds. Treats sewage from Osage City. Population 1910, 2,432; number of connections to sewer in use, 175; number of persons contributing to flow, 875.

Sewage flow. Average season: 28,000 gallons per day.

Rate. Capacity per day: Average season, 32.

Tanks. Number, 1; Type, plain one-story; number of units, 3. Units Nos. 1, 2 and 3: Length, 35 feet; width, 10 feet; depth, 9 feet 6 inches; capacity, 20,500 gallons. Average detention period, 17.5 hours.

Operation cycle, contact beds. Units Nos. 1, 2, 3 and 4. Fill, 30 minutes; empty, 30 minutes; contact, 90 minutes; rest, 6.5 hours. Treatment: 28,000 gallons per day; gallons per acre per day, 291,009.

Timing apparatus. Type, timed siphons; size, 8 inches; make, Miller; units, 4.

Distributing system pipe. Size, 6 inches; number of openings, 11.

Collecting system. Farm tile, size, 4 inches; number of laterals, 16; spaced 3 feet from center to center.

Main Collectors. Size 6 inches.

The above cycle is as it would have been had the contact beds been in working order during the tests.

Sludge beds, none; protected from flood, none; sludge has never been handled.

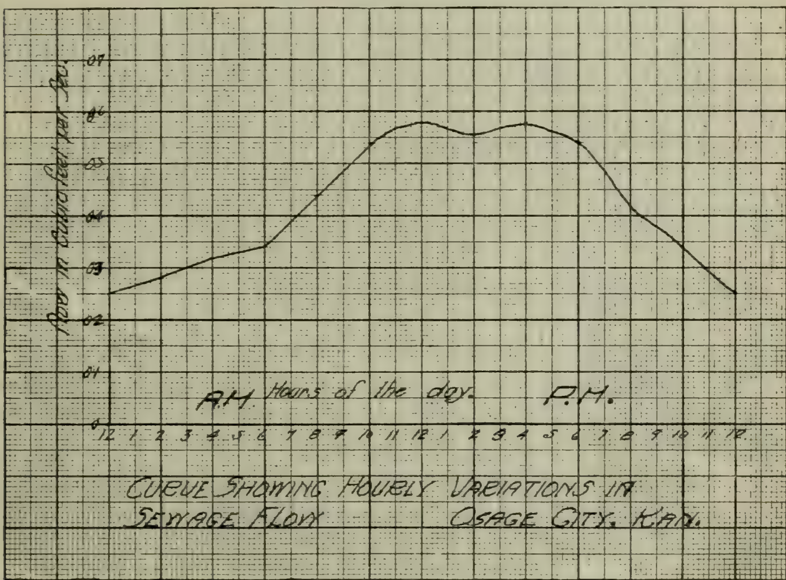

FIG. 20.

Variation of sewage flow during the day at Osage City, Kan.

Figure 20 shows the distribution of the sewage flow through the day.

The plant was in need of immediate attention at the time of the test, owing to leaky pipes in the dosing chamber and dirty contact beds, and it was hoped that it would be cleaned up in time for a second test to be made under more favorable conditions. The necessary improvements were not made, however, and the results of these tests, therefore, must stand out as a "horrible example" of what will happen when a sewage disposal plant is not given proper care.

SEPTIC TANK. The septic tank is made up of three compartments, each holding 17.5 hours' flow, and at the time of the test two of these compartments were in use, giving a detention period

of 35 hours, which was further augmented by a nine-hour period of detention in the dosing chamber. This gives time for vigorous septic action, and the sewage was in very poor condition for contact-bed treatment when it left the septic tank, and in addition to this the proper operation of the contact beds was prevented by leaky piping in the dosing siphons, and the septic-tank effluent was running continuously through one bed and rapidly filling it up with sludge, which was carried over from the septic tank.

The following table shows the efficiency of this plant. Since the contact beds were not operating, the effluent of the plant is merely septic-tank effluent which has been allowed to run through a dirty contact bed.

Percent removal suspended solids.	Percent removal oxygen consumed.	Stability figure.		Dissolved oxygen.		Oxygen demand.	
		Raw.	Effluent.	Raw.	Effluent.	Raw.	Eff.
None.	25	0	*28	0	0.4	93	48

*In 1 to 10 dilutions in city water.

The operation of this plant could have been improved by—

First. Using only one compartment of the septic tank at a time, thus cutting down the detention period to 17.5 hours. An interesting result of the long detention period here is the attacking of the concrete forming the sides and walls of the tank and dosing chamber. The action on the wrought iron manhole covers is also plainly noticeable.

Second. Keeping the piping in the dosing chamber clean and free from leaks.

Third. Keeping the contact beds clean, free from weeds, and watching the timing apparatus.

Fourth. Building a sludge bed and providing means for removal of sludge from the septic tank.

Under regular and efficient supervision this plant is capable of giving fair results, but until it receives such attention it will be a failure.

Newton.

The sewage disposal plant at Newton, Kan., consists of a plain septic tank built in 1912 as the partial fulfillment of a Board of Health suggestion of means to prevent the pollution of Sand creek.

The original sewer system entered the creek at several different points, and therefore the construction of an intercepting sewer was necessary to carry the sewage to the disposal plant. The

plant is subject to rapid and large changes in sewage flow, due to the intercepting sewer along Sand creek being alternately above and below the ground-water level as Sand creek rises and falls. The variation for wet and dry periods as well as for hours of the day is shown in Figure 21. The tank has no means of protection from flood, and a five-foot rise in Sand creek completely sub-

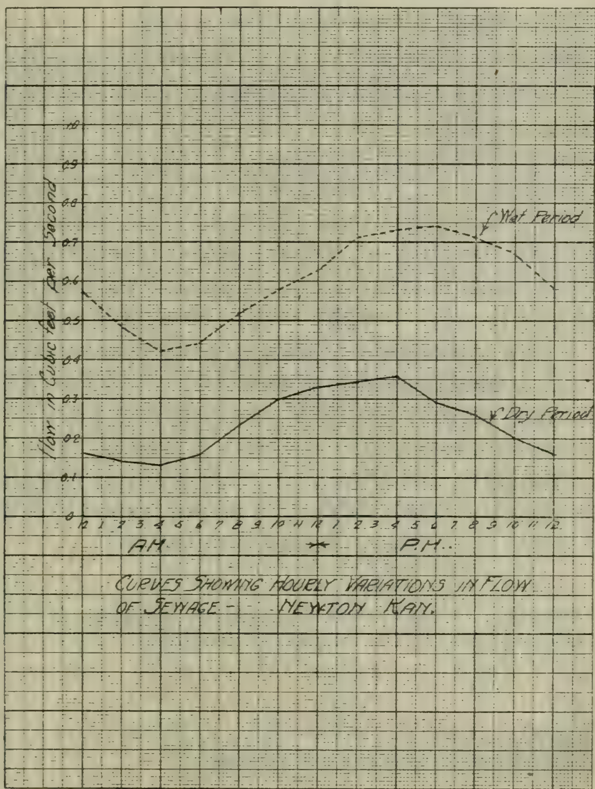

FIG. 21.

Variations in sewage flow at Newton, Kan., for wet and dry seasons.

merges it. No provision for disposal of sludge from this tank is made, further than to allow the sludge to lie in a low spot of ground near the tank until the creek rises sufficiently to carry it away. The sludge is pumped from the tank by a 6-inch steam-driven centrifugal pump.

The following table shows the efficiency of the tank at the two periods tested:

SEASON.	Percent removal suspended solids.	Percent removal oxygen consumed.	Dissolved oxygen.		Oxygen demand.		Detention period, hours.
			Raw.	Effluent.	Raw.	Effluent.	
Dry........	39	43	0	0	132	13	25.2
Wet........	29	23	7.3	5.0	56	60	10.5

These tests show that as far as pollution in the creek is concerned the septic-tank effluent is better than the raw sewage only in that some of the suspended solids are removed, and hence sludge banks are less likely to form. The actual amount of water necessary to dilute the raw sewage is less than that required for the safe dilution of the septic-tank effluent. The reason for this is very plain. At the time of the dry season tests, the tank was operating with both compartments open and the resulting detention period was so long that the sewage became extremely septic, and while a part of the solid organic matter was removed, it was replaced with organic matter in solution. At the time of the tests in the wet season, the tank was badly in need of cleaning and the sewage percolated rather than flowed through the mass of sludge in the tank, and thus the sewage was but little improved.

The following is a brief description of the plant at Newton; and the construction of the plant is shown on Plate C.

Plant at Newton, Kan. Owned by city of Newton. Built in 1912. Consists of septic tank. Treats sewage from city of Newton. Number of connections to sewer in use, 1,173; number of persons contributing, 5,865.

Sewage flow. Wet season, 353,554 gallons per day; dry season, 148,515 gallons per day.

Rate. Capacity per capita per day: Wet, 61 gallons; dry, 26 gallons.

Source of excess flow: ground-water seepage.

Tanks. Number, 1; type, plain; number units, 2. Unit No. 1. Length, 48 feet; width, 16 feet; depth, 8 to 9 feet; capacity, 51,700 gallons. Detention period: Wet, 3.5 hours; dry, 8.4 hours. Unit No. 2: Length, 48 feet; width, 32 feet; depth, 8 to 9 feet; capacity, 103,400 gallons. Detention period: Wet, 7 hours; dry, 16.8 hours.

No sludge beds. A pit is used for sludge drying; drainage is very poor, however, and the sludge is not properly handled. Pumped into pit in thick layers.

This plant as it stands is giving no benefit to the city of Newton and should be either abandoned or supplemented with a more complete method of purification. Further than to remove sludge at necessary intervals, and to shift the sewage from one compart-

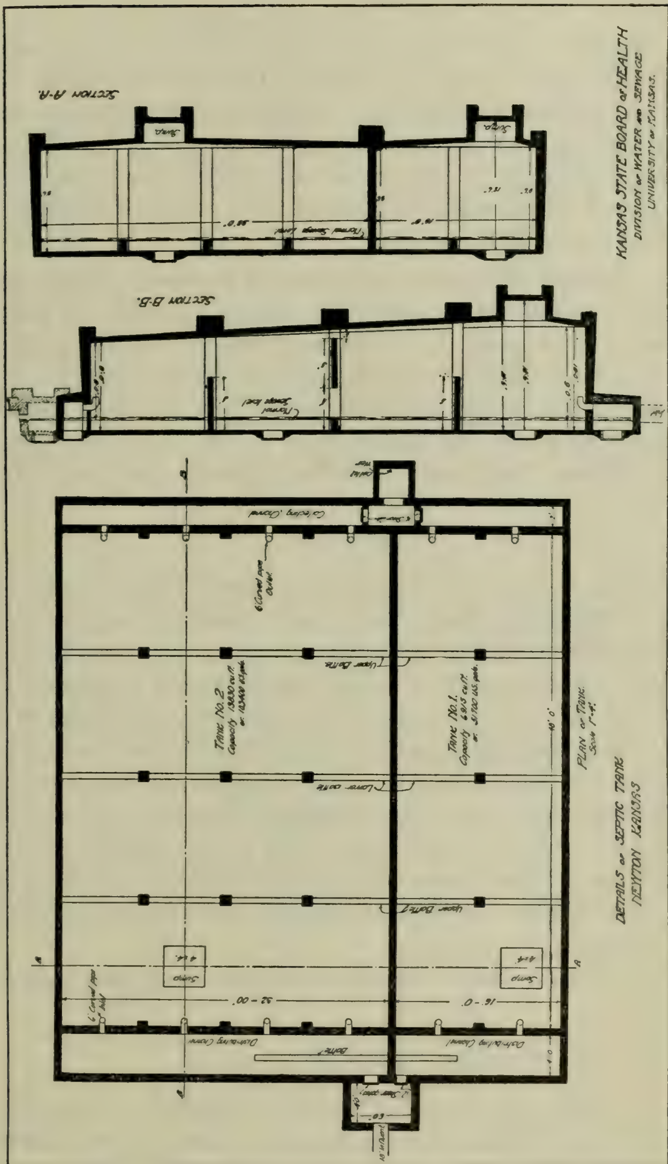

PLATE C.

Showing construction of septic tank at Newton, Kan.

ment to the other, the plant operator has no means of regulating the operation of this plant. A few things, however, should be done:

First. Regulate by ordinance the character of substances allowable in the sewer. During the tests a large amount of garbage and rags and rubbish was found in the sewer, and these are detrimental both to the sewage system and the disposal plant because they promote clogging of the mains and laterals and tend to fill up the disposal plant with substances that will not readily decompose and are hard to remove.

Second. Regular inspection trips should be made to this plant to note the building up of sludge, to change the flow of sewage when necessary, to keep the inlets and outlets free from sludge deposits, and to do whatever odd jobs may be necessary.

When this is done the city will be getting the best possible benefit from this plant, and unless this is done no better results may be expected than were observed during the tests above recorded.

Winfield.

This plant is located on the state property about three miles northeast of Winfield, Kan., and treats sewage from the State Home for Feeble-minded. The sewage from this institution is emptied into Timber creek, a small stream which is tributary to the Walnut river, at a point above the waterworks intake of the city of Winfield, and the plant was built in 1913 for the purpose of protecting this water supply. This institution has a population of approximately 700, all of whom use the sewer. In addition to the sewage from the institution, the plant receives laundry water and some kitchen waste (not garbage) and the flow is subject to abrupt fluctuations, the most important of which are as follows:

6 A. M.—Rising hour is 5:30 to 6.

7 to 8 A. M.—Rise in quantity and strength due to emptying pails from sleeping wards.

8 to 3 P. M.—Numerous fluctuations due to emptying laundry tubs.

9 P. M. to 4 A. M.—Flow drops practically to nothing.

This, of course, has its effect on the operation of the plant, particularly of the Imhoff tank. The plant receives a considerable amount of warm water, and this materially affects the operation of the Imhoff tank by promoting vigorous bacterial action in the sludge digestion chamber.

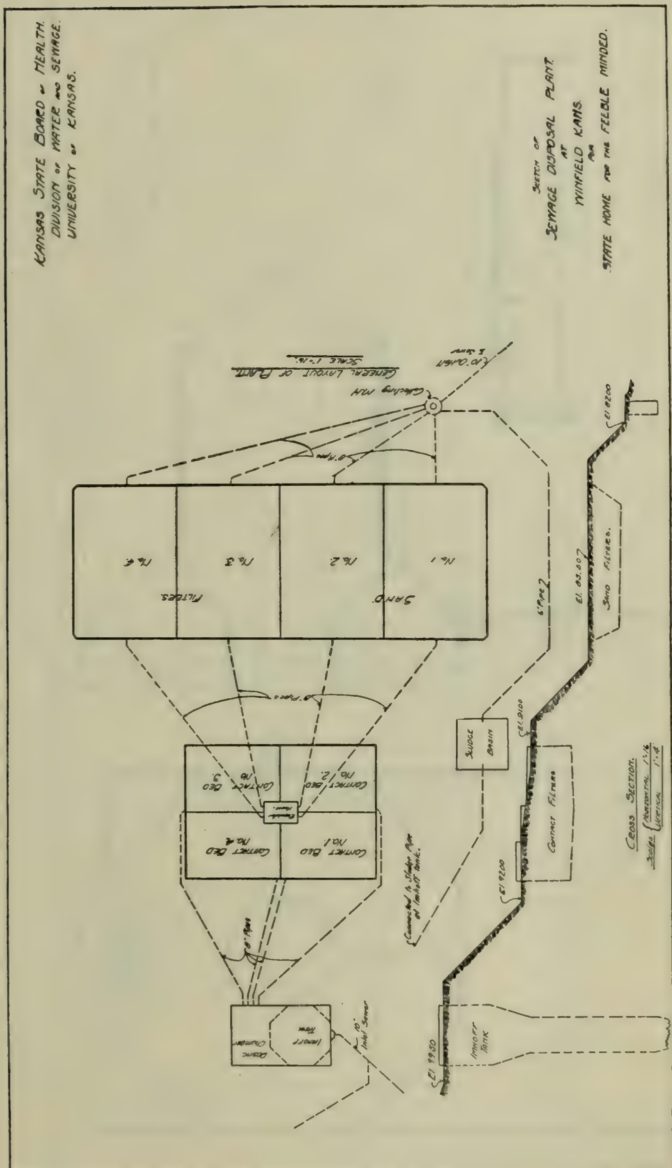

Plate D.

Showing general layout of sewage-disposal plant at the State Home for Feeble-minded at Winfield, Kan.

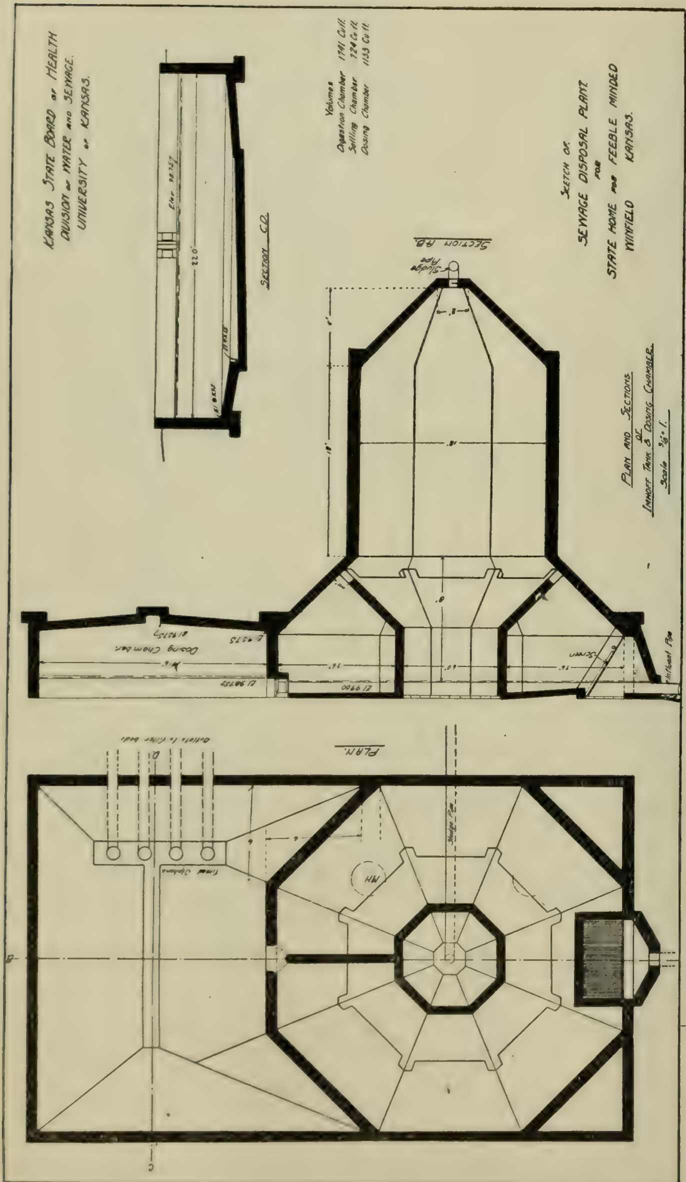

PLATE D$_1$.

Showing construction of Imhoff tank and dosing chamber at the State Home for Feeble-minded at Winfield, Kan.

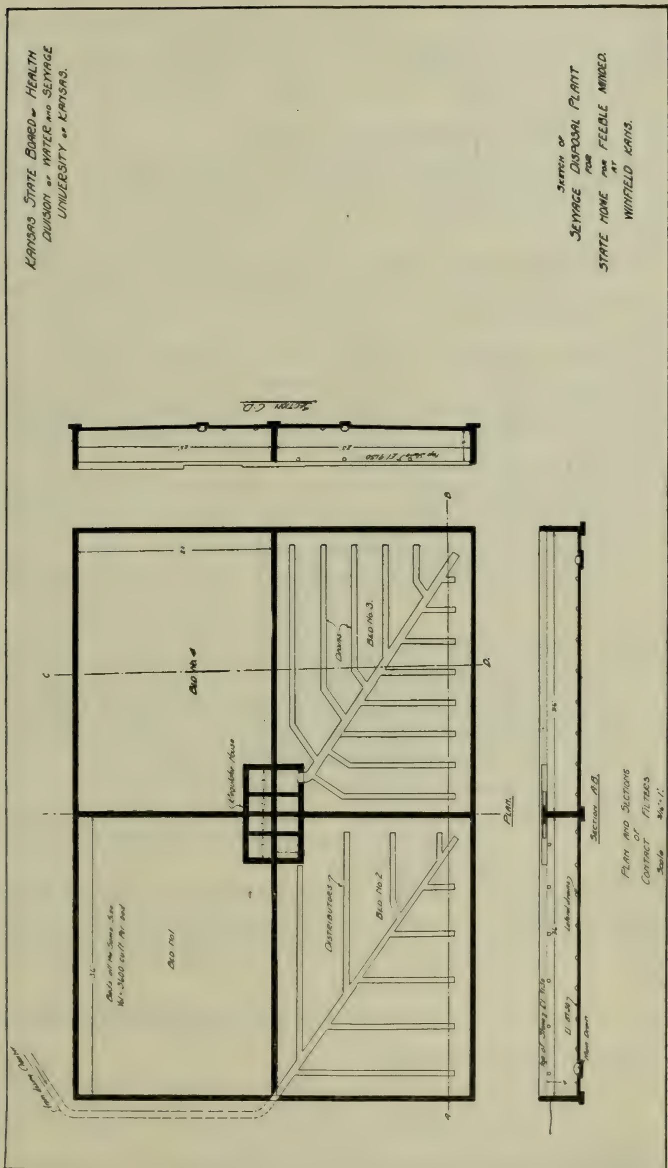

PLATE D_2.

Showing construction of contact beds at the State Home for Feeble-minded, at Winfield, Kan.

The following is a brief description of the plant and its construction is shown on Plates D, D_1 and D_2:

Plant near Winfield, Kan. Owned by State Home for the Feeble-minded. Consists of Imhoff tank, contact beds, sprinkling filters, sludge bed. Built in 1913. Treats sewage from state institution. Persons contributing, 700. Condition of system, good.

Average sewage flow. 32,450 gallons per day.

Tank. Type, Imhoff; number of units, 1; Settling chamber: Capacity, 5,440 gallons; detention period, 4.1 hours. Digestion chamber: Capacity, 31,100 gallons.

Rate. Capacity per day: Average, 40 gallons per capita per day.

Dosing apparatus. Type, plural alternating; size, 8 inches; number units, 40.

Dosing chamber. Effluent depth, 28 inches; capacity, 8,090.

Contact beds. Number, 4. Filling material, broken limestone; size, 1 to 4 inches. Units Nos. 1, 2, 3 and 4: Length, 36 feet; width, 25 feet; depth, 4 feet; cubic gross, 27,000 gallons; capacity, net, 8,000 gallons; percent voids, 29; area, 900 square feet; acres, .0205.

Operation cycle. Units Nos. 1, 2, 3 and 4: Fill, 25 minutes; empty, 20 minutes; contact, 60 minutes; rest, 255 minutes. Rate of treatment per day, 32,450 gallons; per acre per day, 386,000 gallons.

Timing apparatus. Type, timing chamber; size, 8 inches; make, Miller; units, 4.

Distributing system. Covered; size, 6 inches; number of openings, 10.

Collecting system. Size, 4 inches; number of laterals, 12; spaced, 4 feet.

Sludge beds. Number, 1; construction, 6 inches of sand on 1 foot of rock; length, 20 feet; width, 20 feet; area, 400 square feet; drains, size, 4 inches. Flood protection: No need; curbed with dry masonry.

Sludge handled by gravity from Imhoff tank.

Extra plant not listed: Two 15 by 50 feet sprinkling filters, 3½ feet deep, filled 2½ feet with 2-inch rock and 1 foot with rock of large size. Dosed at rate of 943,000 gallons per acre per day.

Remarks: The plant originally had four 40 by 60 feet sand filters, but these became so badly clogged, due to placing stone screenings under the sand, that in 1915 they were discontinued and two experimental trickling filters built.

IMHOFF TANK. The following table shows the efficiency of the Imhoff tank and scum chamber:

Percent reduction suspended solids.	Percent reduction oxygen consumed.	Dissolved oxygen.		Oxygen demand.		Stability figure.		Nitrites.		Nitrates.		Detention period.	
		Raw.	Imhoff tank.	Raw.	Imhoff tank.	Raw.	Imhoff tank.	Raw.	Imhoff tank.	Raw.	Imhoff tank.	Tank, hrs.	Dosing chamber, hrs.
44	36.5	4.0	0	224	315	0	0	–	.16	–	.11	4.1	6

This shows a fair reduction of solids and oxygen consumed, but the effluent was always putrescible and devoid ot dissolved oxygen. This is due to the fact that there is a great amount of gas formed in the central well, and this keeps a portion of the sludge lifted above the slots at the bottom of the settling chamber, so that it is impossible to keep the sludge from mingling with the decomposing sewage. There is no known remedy for this action in this particular tank, but it is generally prevented in the later designs of Imhoff tanks by having a larger vent and by keeping the scum and sludge in this vent broken up. The mingling of the gas-lifted sludge with the flowing sewage was readily shown at the outlet of the Imhoff tank during the earlier part of the tests, but was to some extent checked by cementing 4-inch elbows into the weir so that the sewage would be drawn off one foot below the surface. The percent removal of solids in the Imhoff tank after the installation of these makeshift scum boards was 56 percent, an increase of 12 percent.

The rapid sludge digestion here makes it necessary to remove sludge oftener than is common with this type of tank. It was found that the removal of a small amount each week gave less interruption to the plant and better results than the removal of a larger amount at longer intervals.

SCUM CHAMBER. On account of the freshness of the sewage, there is a great quantity of large floating matter which is removed in the scum chamber. About one wheelbarrow load of this is removed daily and dumped on a hillside back of the plant, where it causes no nuisance on account of the distance from any building. However, these screenings are very offensive, and at the ordinary plant should be buried.

CONTACT BEDS. The contact beds at this plant have really never been given a fair chance, because of the septic character of the Imhoff tank effluent. However, some improvement was effected, as is shown by the following table of results:

Percent removal suspended solids.	Percent removal oxygen consumed.	Dissolved oxygen.		Oxygen demand.		Stability figure.		Nitrites.		Nitrates.		Rate of treatment gallons per acre per day.
		Imhoff tank.	Contact beds.	Imhoff tank.	Contact beds.	Imhoff. tank.	Contact beds.	Imhoff tank.	Contact beds.	Imhoff tank.	Contact beds.	
29	32.8	0	*	315	161	0	11	.16	.26	.11	1.11	386,000

*Trace.

This shows the contact-bed effluent to be unfit to be discharged into a small stream, but it is on the way toward purification, as shown by the increase in nitrates and stability figure. The removal of solids and oxygen consumed is satisfactory. The periods of tests were not long enough to permit of changing the operation cycle.

SAND FILTERS. Originally the plant had four sand filters (as shown on Plate D), and one test was made on these before they became clogged and were replaced with trickling filters. The following table shows the results obtained from use of these filters:

Percent removal suspended solids.	Percent removal oxygen consumed.	Dissolved oxygen.		Oxygen demand.		Stability figure.		Rate of treatment, gallons. per acre per day.
		Contact bed.	Sand filter.	Contact bed.	Sand filter.	Contact bed.	Sand filter.	
12.5	85.5	Trace.	43	161	1200	11	48	162,000

These results show a large increase in stability, oxygen demand, and dissolved, but rather low removal of suspended solids. The effluent requires 30 volumes of water, or 973,500 gallons of water each day, for proper dilution, since this amount is always available in Timber creek, the disposal plant can be said to have been protecting the creek at the time of the tests. The beds worked fairly well for two years, but finally the mass of crushed stone and screenings became so tightly packed that the sewage would not pass through the beds, and in 1915, the beds were cut out and two trickling filters installed where beds 3 and 4 (see Plate D) were located. These filters are 15 feet wide by 50 feet long and 3½ feet deep. They are dosed directly from the contact beds, sufficient natural head being available. The distributors are 2-inch galvanized pipes and the sewage is discharged through eighteen 2 by 2 by ½ in. tees pointed upward. Galvanized-iron dash plates set 3 inches above the opening tend to distribute the sewage over the rock.

The results of tests on these filters are given in the following table:

Percent removal suspended solids.	Percent removal oxygen consumed.	Dissolved oxygen.		Oxygen demand.		Stability figure.		Nitrites.		Nitrates.		Rate of treatment, gallons per acre per day.
		Contact bed.	Trickling filter.	Contact bed.	Trickling filter.	Contact bed.	Trickling filter.	Contact bed.	Trickling filter.	Contact bed.	Trickling filter.	
3	27.4	*	43	161	137	11	15	.26	.27	1.10	4.20	943,000

* Trace.

These tests show that the contact-bed effluent is greatly improved, though not as much as it was in the case of the sand filters. The 34 volumes, or 1,103,000 gallons of water per day, can be counted on from Timber creek.

The efficiency of the total plant, using the trickling filters, is shown in the following table compared with the sand filters:

	Percent removal suspended solids.	Percent removal oxygen consumed.	Oxygen demand.	Dissolved oxygen.	Stability figure.
Sand filters	65.5	93	120	4.3	48
Trickling filters	61.5	69	137	4.3	11

Girard.

The sewer system in Girard was built in 1913, and as no continual stream was available the sewage-disposal plant was built to prevent local nuisances. From the first the plant received no attention, and at the time of the tests in 1915 was in very bad condition. The tanks needed cleaning, the siphons in the dosing chamber failed to work regularly, and during a large portion of the time one contact bed had received the entire sewage flow and was practically choked. The following is a description of the plant, and the construction details are shown in Plates E and E_1.

Plant at Girard, Kan. Owned by city of Girard. Consists of septic tank and contact beds. Built in 1913. Treats sewage from the city of Girard. Number of connections on sewer, 800; in use, 200 (1915); persons contributing, 1,000.

Sewage flow. Average season, 88,000; wet season, overflows.

Excess flow. Source, roof drains and infiltration.

Rate. Capacity per day: Average, 88 gallons per capita per day.

Tanks. Type, plain; number of units, one tank, three compartments. Units Nos. 1, 2 and 3: Length, 39 feet 2 inches; width, 10 feet; depth 9 feet 6 inches; capacity, 22,000; average detention period, 6 hours.

Dosing apparatus. Type, plural alternating; number of units, 4; size, 8 inch.

Dosing chamber. Length, 31 feet; width, 16 feet; effluent depth, 3 feet; capacity, 12,000 gallons.

Contact beds. Number, 4; filling material, Joplin grit, size 2 to 3 inches. Units Nos. 1, 2, 3 and 4: Length, 43 feet; width, 30 feet; depth, 4 feet. Cubic capacity, gross, 38,800; net, 23,500; percent voids, 40.

Timing apparatus. Type, timed siphon; size, 8 inch; make, Miller; units, 40.

Distributing system. Vitrifying pipe; size, 6 inch; number of openings, 7.

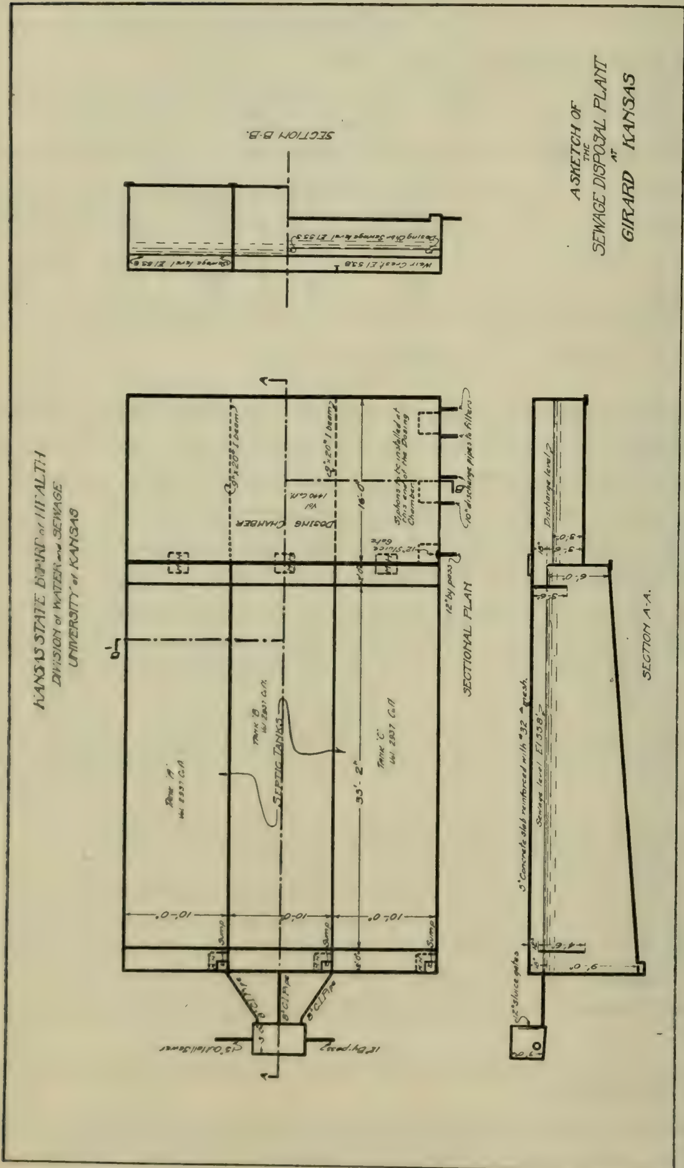

Plate E.

Showing construction of septic tank at Girard, Kan.

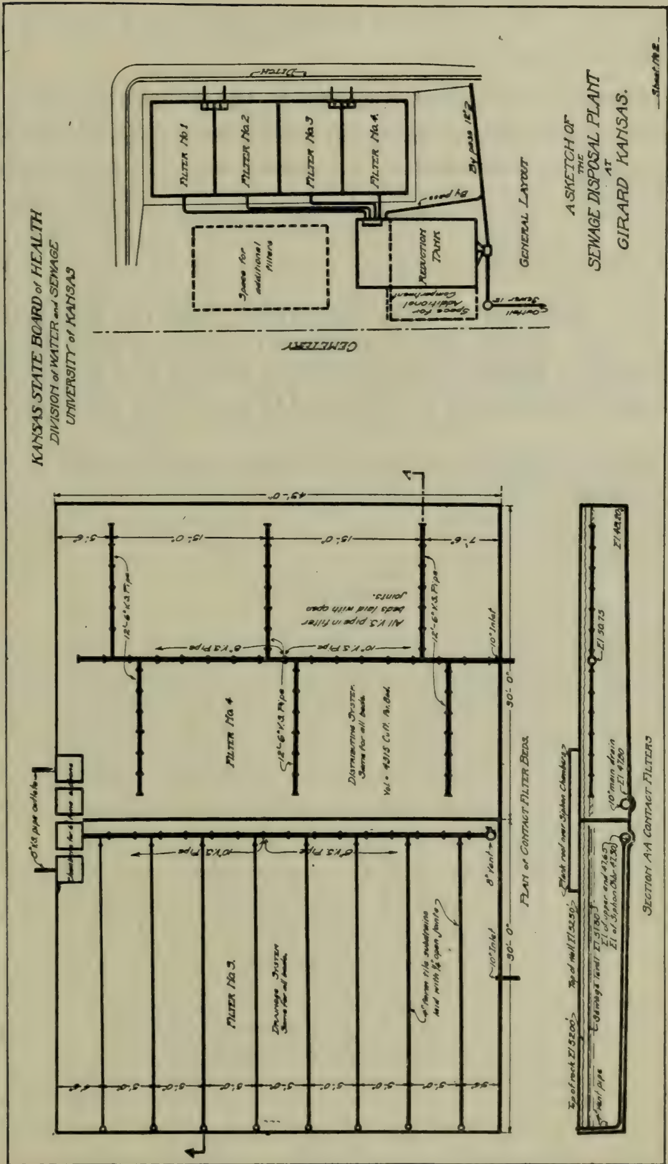

PLATE E₁.

Showing construction of contact beds, Girard, Kan.

Collecting system. Farm tile; size, 4 inch; number of laterals, 8; spaced, 5 feet, center to center.

Main collectors. Size, 8 inch.

No sludge beds. No provision for handling sludge, or for cleaning, other than by pumping through M. H.

The efficiency of this plant is shown in the following table:

Percent removal suspended solids.	Percent removal oxygen consumed.	Oxygen dissolved.		Oxygen demand.		Stability figure.	
		Raw.	Effluent.	Raw.	Effluent.	Raw.	Effluent.
10.5	None.	3.0	0	86	123	0	0

This shows that the effluent was worse than the raw sewage during the test. This is easily explained by the fact that the tank and beds were so badly clogged that the sewage had to percolate through them, and picked up putrescible matter on the way.

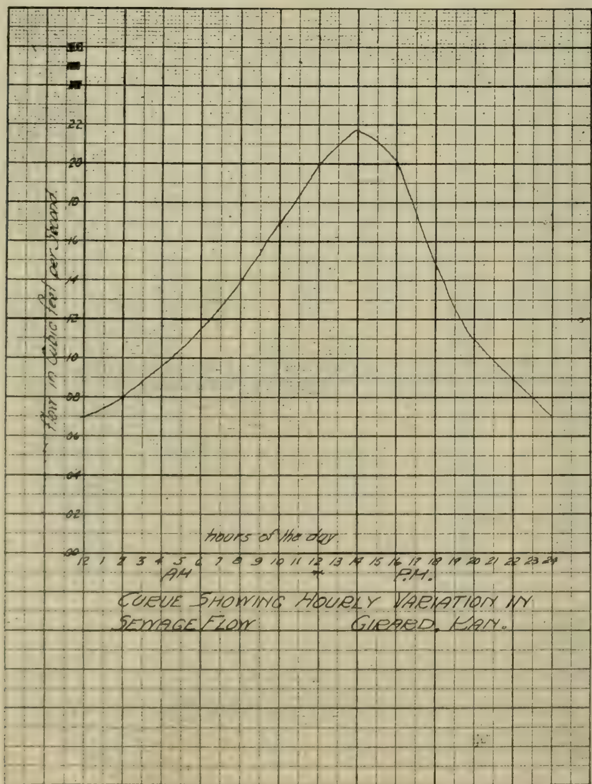

FIG. 22.

The tank has been operating with three compartments in parallel, with a resulting detention period of eighteen hours, which is too long. Better results would be obtained with the use of the compartments one at a time.

The concrete forming the top and sides of the septic tank and dosing chamber is disintegrated to a depth of one-fourth to one-half inch. This is directly the result of the excessive putrefaction due to the long detention period. There are several structural defects in this plant which should be remedied at once. They are:

1. Leaks in the walls between contact beds.
2. Lack of valves to cut off plant when the creek level is higher than the floor of the timing chamber.
3. No sludge bed or means of cleaning tanks.

The plant is subject to rapid changes in sewage flow at times of storm, owing to leaky sewers and to roof drains which are connected to the sewer contrary to ordinance.

These things make attention absolutely necessary at this plant, and it is not surprising that it is giving such poor results, considering its two years of neglect.

Independence.

This plant was built in 1907 to care for the sewage from the west-side sewer district of the city of Independence. The effluent enters Rock creek at a point about two miles above its junction with the Verdigris river, and it was with the object of preventing nuisances along this creek that the plant was built. The main sewer leading to this plant is extremely leaky, and as a result this plant is subject to rapid fluctuations in sewage flow (see Fig. 23), and it is necessary at such times to by-pass the sewage around the plant to prevent its being flooded, with the result that the operation of the septic tank and contact beds is interrupted. This can be prevented by the construction of an interceptor on the main sewer above the plant, so designed that all sewage in excess of the maximum capacity of the plant will be automatically by-passed to the creek, and will protect the plant at all times except when the water level in Rock creek is higher than the outlet of the contact beds, at which times it is necessary to close the hand-operated valves at each end of the plant and cut it completely out until the creek goes down.

The following is a brief description of this plant. (Construction details are shown on F and F_1.)

Plant at Independence, Kan. Owned by city of Independence. Built in 1907. Consists of septic tank and contact beds. Treats sewage from west-side district. Number of connections to sewer in use, 262; persons contributing to system, 1,310.

Sewage flow. Average season, 264,300.

Source of excess flow. Leaky sewers.

Rate. Capacity per day: Average, 211 gallons per capita per day.

Tanks. Type, one story; number of units, one tank, two compartments. Unit No. 1. Length, 60 feet; width, 20 feet; depth, 85 feet; average gross capacity, 76,500 gallons; detention period, average season, 7 hours. Unit No. 2: Length, 60 feet; width, 10 feet; depth, 85 feet; average gross capacity, 38,250 gallons; detention period, average season, 3.5 hours.

Dosing apparatus. Type, Cameron; number of units, two sets, four each.

Contact beds. Number, 8; filling material, Joplin chats, size, ¼ to ½ inch. Units Nos. 1 to 8: Length, 50 feet; width, 40 feet; depth, 3 feet, 6 inches. Cubic capacity: Gross, 52,500 gallons; net, 21,000 gallons; percent voids, 40. Area, feet, 2,000; area, acres, .046.

Operation cycle. Units 1 to 4: Fill, 1.8 hours; empty, 30 minutes; con-

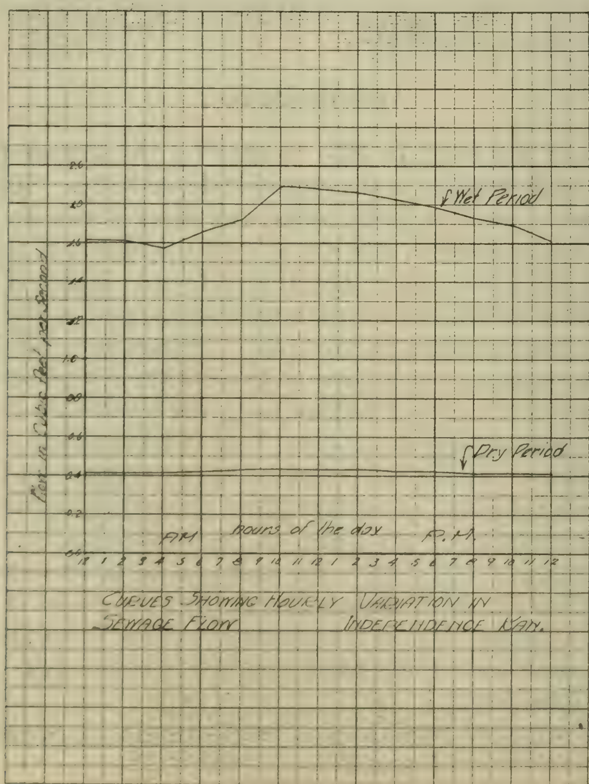

FIG. 23.

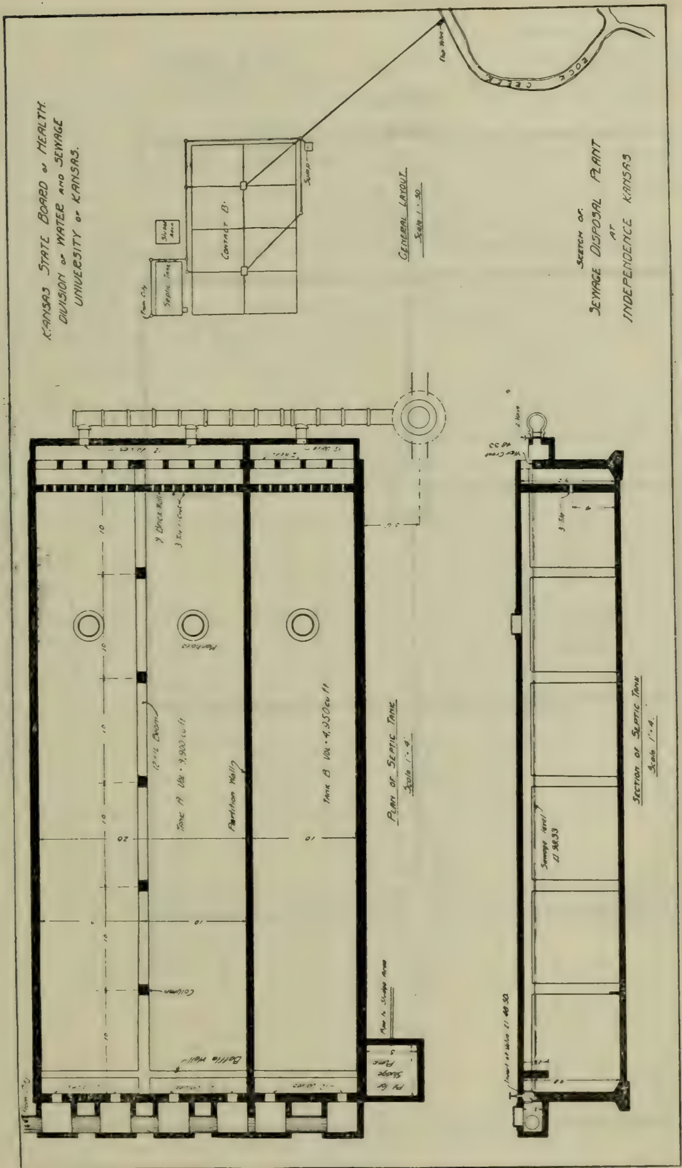

PLATE F.

Details of septic tank, Independence, Kan.

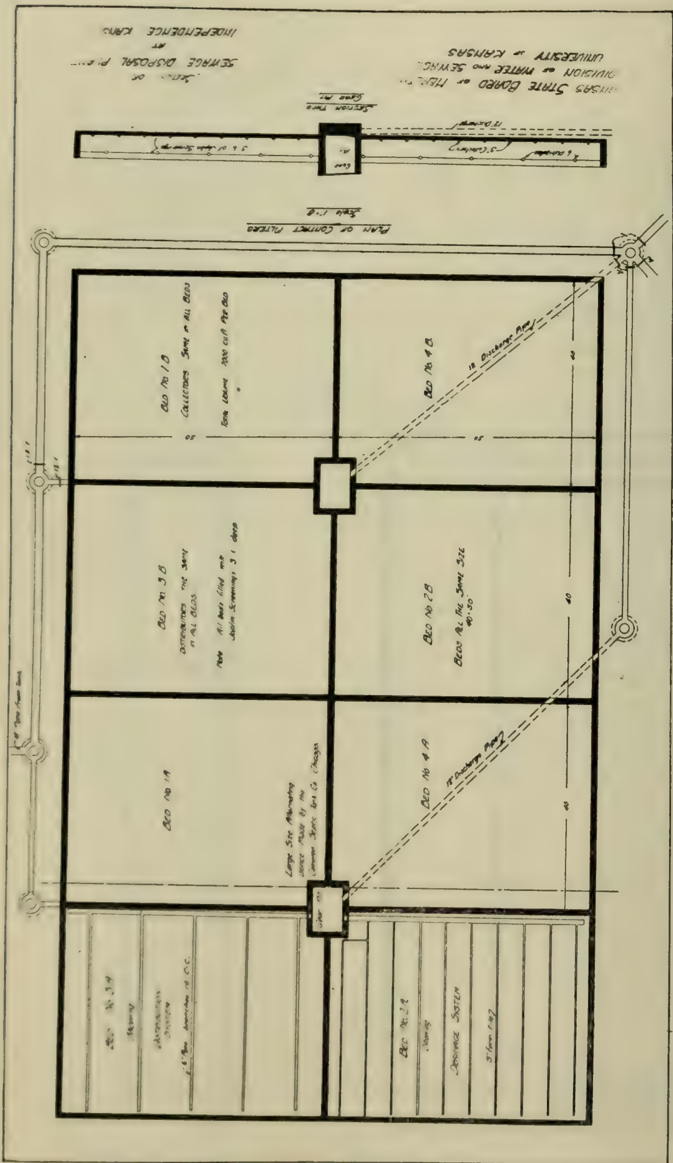

PLATE F_1.
Details of contact beds, Independence, Kan.

tact, 2 hours; rest, 3 hours. Treatment, gallons per day, 264,300; gallons per acre per day, 1,586,000.

Timing apparatus. Type, float controlled; size, 6 inch; make, Cameron; Units, 8.

Distributing system. On surface; size, 6 inch; number of openings, 50.

Collecting system. Tile; size, 3 inch; number of laterals, 10; spaced, 5 feet, center to center.

Main collectors. Size, 6 inch.

General. The Cameron dosing device necessitates continuous operation, and hence the cycle varies with the fluctuations in sewage flow.

Sludge beds. None. There is a pit which has been used for a sludge bed, but no well-designed sludge bed is in existence.

How is sludge handled. Sludge was originally pumped by a 3-inch centrifugal pump, but this was discarded in favor of a bucket pump in 1916. This pump has given excellent service.

The efficiency of the septic tank is shown in the following table:

Percent removal suspended solids.	Percent removal of oxygen consumed.	Oxygen dissolved.		Oxygen demand.		Stability figure.		Detention period.
		Raw.	Septic.	Raw.	Septic.	Raw.	Septic.	
29.6	21	5.6	5.2	32	44	90	90	7.0

This shows rather low reduction in solids and oxygen consumed, but this can be expected with such dilute raw sewage. The oxygen demand shows higher in the septic-tank effluent than in the raw sewage, showing that some of the soluble organic matter in the tank was being removed. This is really not a very fair test on this tank owing to the weak sewage, which is an unusual condition here. However, it is fairly characteristic of wet-weather operation of plants which treat sewage from leaky sewers.

The following table shows the efficiency of the contact beds:

Percent removal suspended solids.	Percent removal of oxygen consumed.	Oxygen dissolved.		Oxygen demand.		Stability figure.	
		Septic.	Contact.	Septic.	Contact.	Septic.	Contact.
59.6	50	5.2	7.7	44	18	90	90

This shows that the contact beds were doing excellent work at the time of the tests, and a comparison of these results with those of other beds which treat septic-tank effluent will show how much difference the character of the septic tank effluent makes in contact-bed operation. The fresher the septic-tank effluent can be

kept the better. The efficiency of the entire plant is shown in the following table:

Percent removal suspended solids.	Percent removal oxygen consumed.	Oxygen dissolved.		Oxygen demand.		Stability figure.	
		Raw.	Contact.	Raw.	Contact.	Raw.	Contact.
71.5	61	5.6	7.7	32	18	90	90

This illustrates good operation for a plant of this type.

The dosing apparatus at this plant is of the Cameron type and the operating cycle of the contact beds depends entirely on the sewage flow, since the beds are dosed in rotation. Therefore, it is hard to compare the different parts of the cycle at the plant with those of other plants. The keynote of the operation of this plant, however, is that the sewage is kept fresh entirely through the process.

This plant is badly in need of a properly made sludge bed, since, if the septic tank is to be operated merely as a settling tank more sludge may be expected, and its removal will be necessary at frequent intervals.

Cherryvale.

The septic tank at Cherryvale was built in 1906, but in 1909 it was remodeled and the contact beds were added. The effluent of this plant enters Drum creek, which is tributary to the Verdigris river, at a point above the waterworks of Coffeyville, and the object of its installation was the protection of this water supply and the prevention of local nuisances along Drum creek. The sewage flow is subject to wide variation, due to leaky sewers and low manholes, and the flow has been known to reach 300 to 400 percent of the average in the space of a few hours after a storm, and since no automatic apparatus is provided to protect the plant at such times, the success of this plant depends on careful watching.

The excess flow is detrimental to the plant operation for several reasons.

1. It stirs up sludge in the septic tank and causes this sludge to be carried over and deposited on the contact beds.

2. It consists very often of muddy water, and this mud accumulates in the crevices of the contact-bed ballast and tends to clog them.

3. It causes the beds to fill so rapidly that the four of them are filled before the first one has had its contact period and emptied.

This, of course, causes the sewage to flow continuously through this bed until the dosing siphons are changed by hand. This condition can not be stopped readily, but the plant can be protected by an interceptor which will divert all sewage over the maximum flow into the by-pass line at times of high water. In this same connection, the small difference in elevation between the creek level and the level of the timing chambers deserves attention, for, as it is now arranged, a very small rise in the creek serves to break the seals in the timing chambers. This fault can and should be remedied either by an automatic or a hand-operated by-pass which will shut off the plant when the creek rises.

The difference in flow for wet and dry periods is shown in Figure 24.

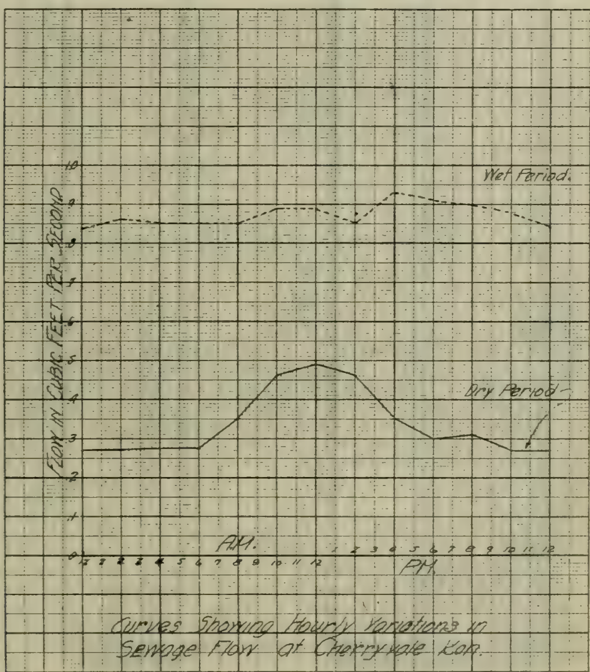

FIG. 24.

Hourly variation in sewage flow, Cherryvale, Kan., during wet and dry periods.

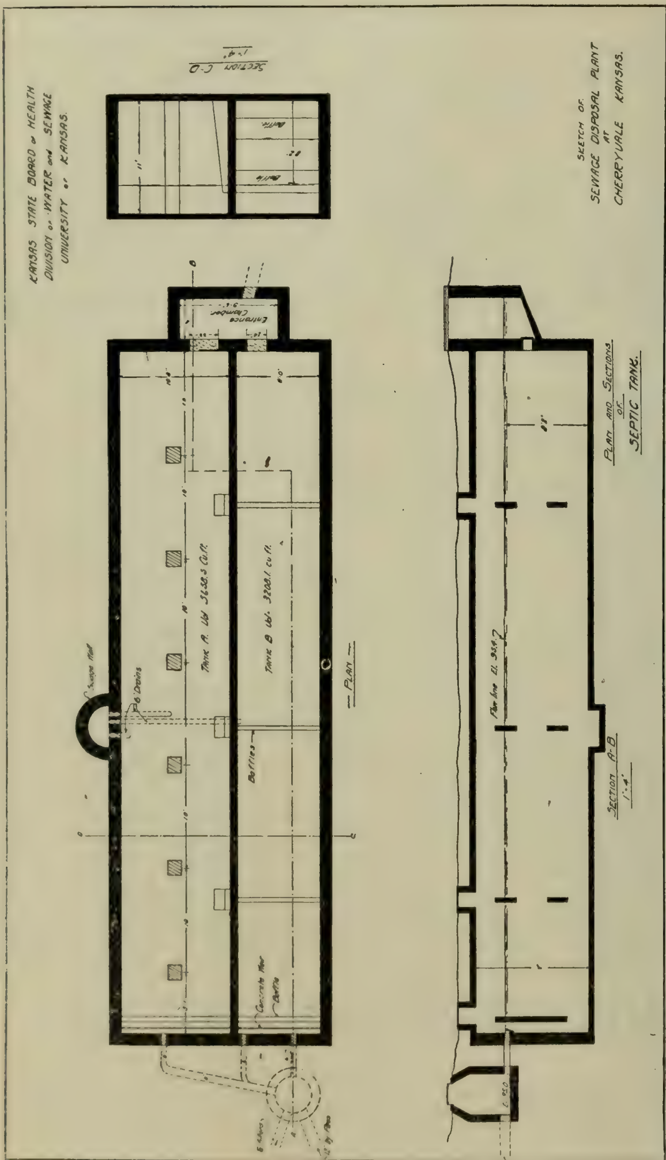

PLATE G.

Details of septic tank, Cherryvale, Kan.

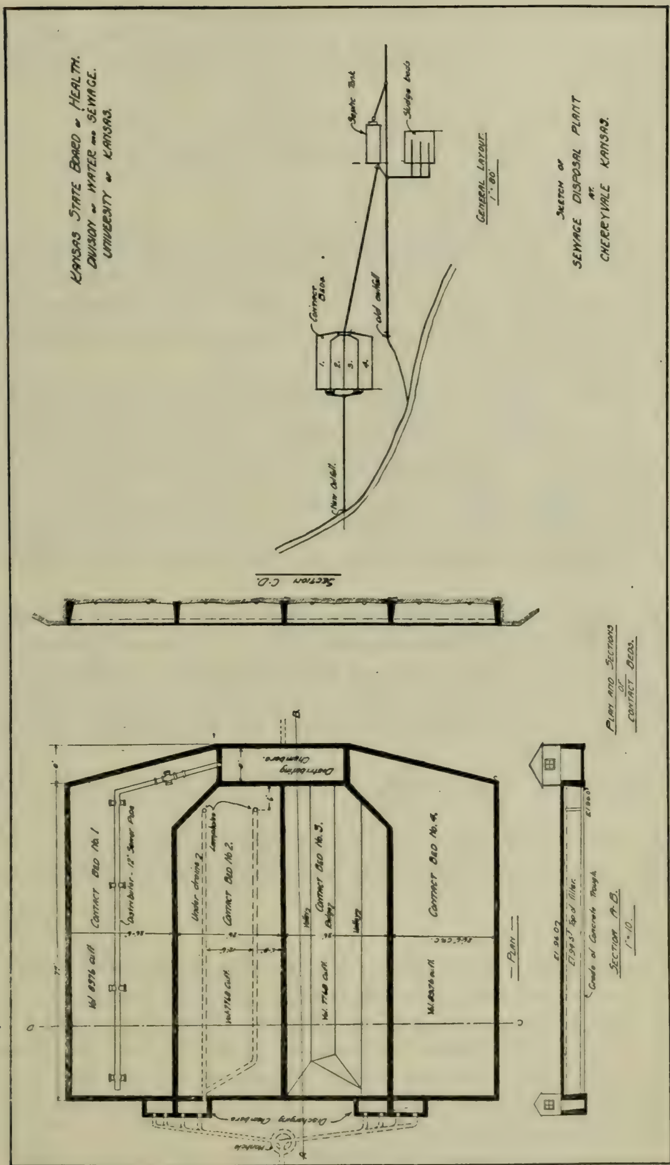

PLATE G1.

Showing details of contact beds at Cherryvale, Kan., and general layout of sewage disposal plant.

The following is a brief description of the Cherryvale plant. Details of its construction are shown in Plates G and G_1.

Plant at Cherryvale, Kan. Owned by city of Cherryvale. Consists of septic tank and contact beds. Built in 1906; remodled in 1909. Number of connections to sewer in use, 275; persons contributing, 1,375. Condition of system, leaky.

Sewage flow. Average season, 220,700; wet season, 741,000.

Rate. Capacity per day: Wet, 540 gallons; average, 161 gallons.

Source of excess flow. Surface water.

Tanks. Type, plain; number units, one tank, two compartments. Unit number A: Length, 65 feet; width, 10 feet, 8 inches; depth, 8 feet, 2 inches; capacity, 42,500 gallons. Detention period: Average, 4.6 hours; wet, 1.4 hours. Unit number B: Length, 65 feet; width, 8 feet, 10 inches; depth 8 feet, 2 inches; capacity, 32,000 gallons. Detention period: Average, 3.5 hours; wet, 1.04 hours.

Dosing apparatus. Type, Airlock feeds; size, 8 inch; number units, 4.

Contact beds. Number, 4; Filling materials, zinc retorts (broken), size 2 to 4 inches. Units Nos. 1 and 4: Length, 77 feet; width, 26 feet; depth, 4.16 feet. Cubic capacity, gross, 67,200 gallons; net, 14,850 gallons; percent voids, 22. Area, square feet, 2,152; acres, .0495. Units Nos. 2 and 3: Length, 70 feet; width, 26 feet; depth, 4.16 feet. Cubic capacity, gross, 58,300 gallons; net, 11,880 gallons; percent voids, 21. Area, square feet, 1,926; acres, .044.

Operation cycle, average period. Units Nos. 1 and 4: Fill, 81 minutes; empty, 20 minutes; contact, 60 minutes; rest, 50 minutes. Rate of treatment, gallons per day, 69,500; gallons per acre per day, 1,390,000. Units Nos. 2 and 3: Fill, 65 minutes; empty, 20 minutes; contact, 60 minutes; rest, 80 minutes. Rate of treatment, gallons per day, 62,500; gallons per acre per day, 1,390,000.

Timing apparatus. Type, timing chamber; size, 8 inch; make, Miller; units, 4.

Collecting system. Tile; size, 12 inch; number of openings, 5.

Collecting system. Farm tile; size, 6 inch; number of laterals, 2; spaced, 12.5 feet, center to center.

Main collector. 8 inch.

Average season cycle. Units Nos. 1 and 4: Fill, 96 minutes; empty, 20 minutes; contact, 60 minutes; rest, 86 minutes. Rate of treatment, gallons per day, 58,500; gallons per acre per day, 860,000. Units Nos. 2 and 3: Fill, 18 minutes; empty, 20 minutes; contact, 60 minutes; rest, 102 minutes. Rate of treatment, gallons per day, 51,700; gallons per acre per day, 860,000.

No sludge beds. No flood protection. Sludge is removed from tank by buckets and dumped on surrounding low ground.

Spillway in by-pass manhole so arranged that only 11,000 gallons per hour reached the contact beds.

Septic Tank. The efficiency of the operation of the septic tank for the two periods is shown in the following table:

Period.	Percent removal suspended solids.	Percent removal oxygen consumed.	Dissolved oxygen.		Oxygen demand.		Stability figure.		Detention period, hours.	Remarks.
			Raw.	Septic.	Raw.	Septic.	Raw.	Septic.		
Dry.....	22	None.	4.5	4.5	48	21	40	75	8.10	Needs cleaning.
Wet.....	85	34	6.0	5.5	50	17	90	90	2.44	Clean tank.

These results show that the plant was not doing very well during the dry period, although the detention period was rather short and the effluent was not septic. This can be explained by the fact that the tank was badly in need of cleaning and the space for sewage flow was so constricted that the detention period was really a great deal less than 8.10 hours, and the sewage in passing over the decomposing sludge picked up soluble products of decomposition in sufficient quantities to render the oxygen consumed content of the effluent equal to that of the raw sewage. The results for the wet period, however, are very good, and the effluent produced is of good character for contact-bed treatment.

Contact Beds. Although the total sewage flow was treated in the septic tank, the contact beds could not stand the strain and an interceptor was placed in the manhole below the septic tank to divert excess flow. The maximum allowed in the beds was 11,000 gallons per hour, and the operation cycle was figured from this amount, since with the exception of only a few days the beds were treating the maximum amount passed by the interceptor.

The efficiency of the beds is shown in the following table:

Period...	Percent removal suspended solids.	Percent removal oxygen demand.	Dissolved oxygen.		Oxygen demand.		Stability figure.		Nitrites.		Nitrates.	
			Septic.	Contact.	Septic.	Contact.	Septic.	Contact.	Septic.	Contact.	Septic.	Contact.
Dry..	32	46	4.5	8	12.5	7	75	80	......	......	......	......
Wet.	25	44	5.5	4.6	4	1	90	90	12	16	.29	.46

These tests show the better effluent to be produced during the wet period, although the percentage removal of suspended solids and oxygen consumed was slightly higher during the dry period. Toward the end of the tests the beds became badly clogged due to several floodings, and the beds can never be expected to do their best work until the ballast is removed and the deposits of mud

removed. The ballast of these beds is composed of broken retorts and slag from zinc furnaces, and while more friable and porous than limestone, it has given very good service. It furnishes more surface for aëration and bacterial action than stone, owing to its irregular shape, and the only drawback is its tendency to crumble. When this ballast is cleaned the extent of this trouble may be known, but at the present time the only indication is the fact that measured by the sewage dose, the percent voids in the ballast has decreased from 40 percent to 25 percent, showing either excessive clogging, or compacting, of the beds.

The efficiency of the plant as a whole is shown in the following table:

PERIOD.	Percent removal suspended solids.	Percent removal oxygen consumed.	Stability figure.	
			Raw.	Effluent.
Dry	47.4	46	40	80
Wet	80.5	63	90	90

These tests show good results for the wet period.

Mr. J. W. Pearce made relative stability tests on the plant from May 3, 1915, to December 26, 1915, and the results of his tests are given in the following table:

DATE SAMPLED.	Relative stability.			DATE SAMPLED.	Relative stability.		
	Raw.	Septic.	Contact.		Raw.	Septic.	Contact.
5- 3-15	84	84	84	9-13-15	0	0	0
5-10-15	84	84	84	9-20-15	11	11	37
5-17-15	84	84	84	9-27-15	21	21	37
5-25-15	84	84	84	10- 4-15	50	37	60
5-31-15	84	84	84	10-11-15	37	3	84
6- 7-15	84	84	84	10-18-15	50	75	84
6-14-15	....	....	....	10-25-15	80	68	84
6-21-15	90	95	96	11- 1-15	21	0	21
6-29-15	50	80	96	11- 7-15	2	0	37
7- 5-15	50	80	96	11-14-15	37	0	21
7-12-15	21	21	84	11-21-15	27	0	21
7-19-15	21	21	75	11-28-15	37	0	21
7-27-15	21	5	50	12- 5-15	37	0	21
8- 2-15	21	37	75	12-12-15	0	50	60
8- 9-15	....	....	....	12-19-15	37	0	21
8-16-15	5	0	21	12-26-15	37	0	21
8-23-15	7	7	21				
8-30-15	21	21	50	Average	40	37	58
9- 6-15	7	21	21				

This table shows that the plant gave a fair effluent for the greater part of the time.

El Dorado.

The plant at El Dorado was built in 1915 with the intention of the prevention of the pollution of Walnut river, which is used as a source of water supply by the cities of Augusta, Douglass and Winfield, all of which are situated below the El Dorado outfall. Since the sewer system was in place when the plant was built, and had been in use for several years, the flow to the plant could be readily determined, and as a result this plant started off with the designed amount of sewage, which is a great advantage to any plant.

The following is a brief description of the plant. Details of construction are shown in Plate H.

Plant at El Dorado, Kan. Owned by the city of El Dorado. Consists of septic tank, sludge bed and sterilizing plant. Built in 1915. Treats sewage from El Dorado, Kan. Number connections to sewer, 850; in use, 315; persons contributing, 1,575.

Rate. Capacity per day, average, 105 gallons per capita per day.

Tanks. Type, plain. Number of units, one tank, two compartments. Units Nos. 1 and 2: Length, 58 feet; width, 18 feet; depth, 7, 5, 8 feet; capacity, 62,640; average detention period, 7.9 hours.

No dosing apparatus. No contact beds.

Sludge beds. Number, 1; construction, rectangular; length, 60 feet; width, 20 feet; underdrains, 6-inch tile, 5 feet, center to center. Protected from flood by automatic float-controlled by-pass. Net area, 1,200 square feet. Not curbed; banks slide badly. Sludge pumped from pump pit by 10 h. p. gasoline engine and 6-inch centrifugal pump.

Extra plant. Chlorine meter; Electro Bleaching Gas Company. Capacity, 30 ounces per hour. Set of mixing channels for the treatment of sewage with chloride. Solution tanks and orifice boxes for chloride of lime treatment when this is desired.

This is the first plant in this state designed to sterilize the septic-tank effluent rather than treat it by ordinary methods. The results of chemical and bacterial tests are given in full in tables in the appendix.

The following table shows the efficiency of the septic tank:

Percent removal suspended solids.	Percent removal oxygen consumed.	Detention period.	Dissolved oxygen.
64	38.5	7.9	*0

*Dissolved oxygen present during night and early morning.

This shows very good work for the septic tank. The percent removal of solids and oxygen consumed was increased by running the septic-tank effluent through the contact chambers. The per-

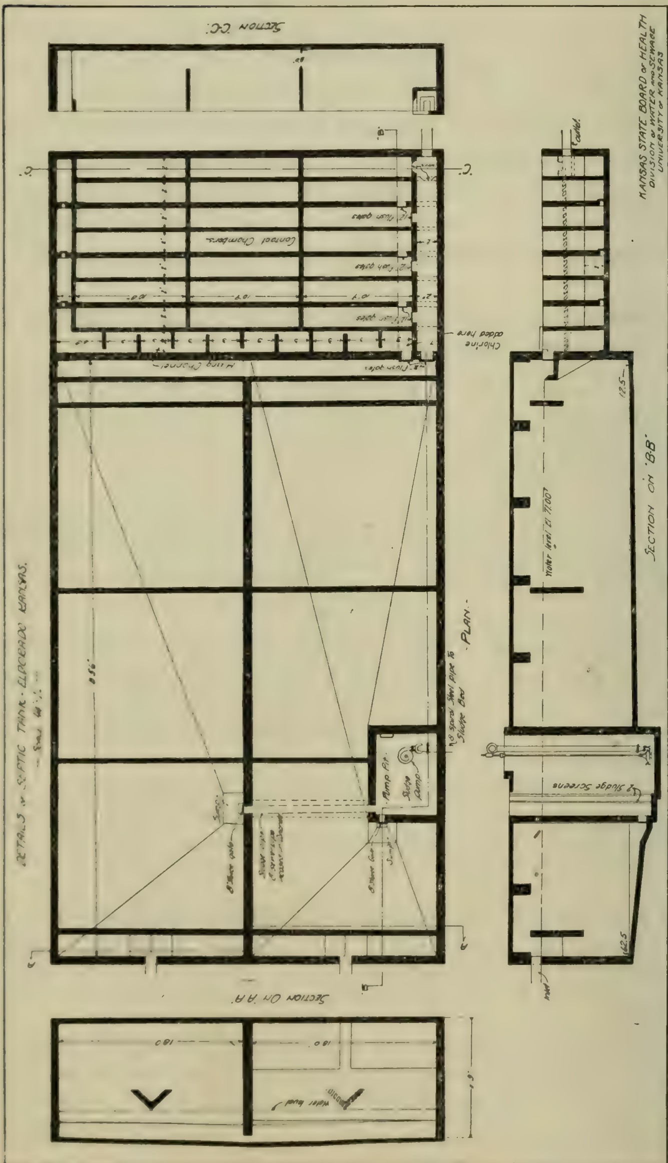

Plate H.

Showing details of construction of septic tank and contact chambers at El Dorado, Kan.

cent removal for one hour contact period was 13 percent for solids and 6.5 percent for oxygen consumed, while for the two-hour period there was no removal of solids and 13 percent for oxygen consumed. This gave an effluent for sterilization that was fairly free from solid matters and not over septic. Tests were made on the relative efficiency of the treatment by chlorine, both on the tank effluent and on the raw sewage, before it entered the tank, and although the tests showed little difference in efficiency of the chlorine, they were not carried over a long period to warrant any change from the generally accepted theory that it is better to treat the effluent.

An examination of Table No. 25 (appendix) shows a few rather widely varying results, as may be expected of bacteriological work done under such conditions. (The laboratory was set up in a construction shed at the plant.) However, the following conclusions may be derived:

5 parts per million will kill 89 percent of all bacteria and 95 percent of those forming red colonies on L. L. agar.

7 parts per million will kill 99.6 percent of all bacteria and 99.8 percent of those forming red colonies on lactose litmus agar.

10 parts per million will kill 99.8 percent of all bacteria and 99.9 percent of those forming red colonies on lactose litmus agar.

The average number of bacteria in raw sewage and contact-bed effluent at different times during the day is as follows (total counts and red colonies on lactose litmus agar incubated on 37° C. for 24 hours):

	Total.	Red col.
Raw sewage:		
7:00 a. m.	125,300	27,100
10:00 a. m.	577,400	67,700
2:00 p. m.	224,900	75,300
5:00 p. m.	151,000	38,300
Septic tank effluent:		
7:00 a. m.	75,500	19,800
10:00 a. m.	108,300	24,000
2:00 p. m.	106,700	26,900
5:00 p. m.	116,700	34,300

The above results show that the complete sterilization of the sewage will require considerable more than ten parts per million of chlorine, while five parts per million will kill 89 percent of the bacteria. Therefore it is a problem of balancing the feed with the amount of purification needed. It is doubtful whether the removal of more than 89 percent is necessary except at times of extremely

low water, when, of course, the chemical feed should be increased. Smaller amounts than five parts per million of chlorine gave very poor results, due to septic action in the mixing chambers. However, with larger amounts of chlorine this did not occur, presumably owing to the larger amount of disinfectant available for keeping down bacterial action in the sludge at the bottom of the chambers. Since this plant relies upon the action of a chemical

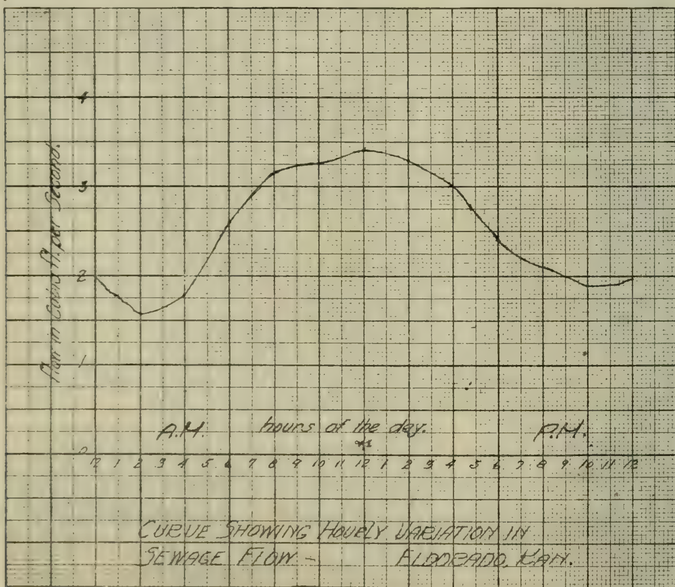

Fig. 25.

Showing hour variation in sewage flow at El Dorado, Kan.

Error.—Read "flow in cubic feet per second" as flow in $\frac{1}{10}$ cubic feet per second.

to render it fit character to enter Walnut river, it is of prime importance that the proper amount of this chemical be fed *at all times*. Therefore, this type of plant must receive more careful attention than ordinary types. The following points should be observed:

1. The daily variation of sewage flow should be ascertained and the proper amounts of chlorine for use at different times calculated. The variation during the test is shown in Figure 25. For convenience in feeding the chlorine, two periods were chosen, one from 8 a. m. to 5 p. m., with an average flow of .282 cubic feet per second, and requiring 1.01 oz. of chlorine per hour for a feed

of one part per million; and the other from 5 p. m. to 8 a. m., with an average flow of .194 cubic feet per second and requiring a feed of .7 oz. of chlorine per hour for a feed of one part per million. The plant operator can set his feed for the day at 8 a. m. and for the night at 5 p. m.

2. The machines for handling liquid chlorine require more than ordinary care for their operation, owing to the corrosive properties of chlorine gas when in presence of air or water, and vigilant search should be made daily for leaks and stoppages, and any leaks found should be repaired *at once,* before the escaping gas has time to corrode the rest of the machine. Generally the nose is a sufficient guide for leaks, but for extremely small ones a bottle of strong ammonia water is necessary. The presence of a leak is shown by the formation of a white cloud of ammonium chloride when the bottle is brought near the leak. A complete kit of repair parts for the chlorine machine should be kept constantly on hand. This practice, while somewhat expensive, is much cheaper in the long run.

3. *Too much care cannot be exerted* in handling the chlorine gas itself, as it is extremely irritating to the nose, eyes and mouth, and if too dense may even cause death. Cylinders of gas should not be allowed to get too hot (not over 125° F.) and should be examined for leaky valves, etc., from time to time.

4. The engine and pump for removing sludge from this septic tank should be kept in working condition, and the tanks should be cleaned out whenever the need is shown by the character of the effluent or by the sludge measurements in the tank. Sludge should be removed when not over four feet has accumulated.

The history of this plant during the two years following these tests shows plainly the economy of having the plant attended. During the spring and summer of 1916 the chlorine machine was not watched very carefully, with the result that it became a complete wreck and the money the city spent for its replacement far exceeded the amount necessary for providing sufficient competent attention for a year, and in addition to this, the prime object of the plant—that of protecting the Walnut river—was for the period defeated.

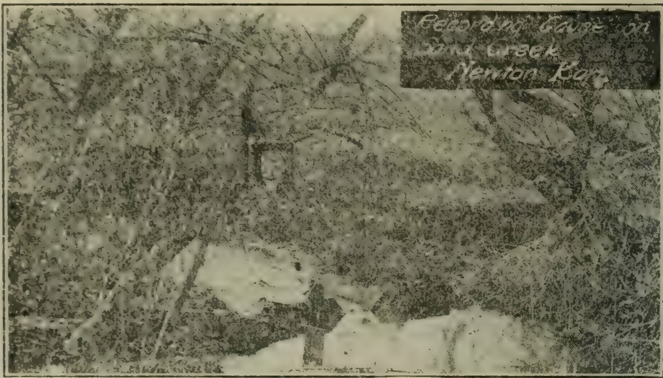

PLATE I.

Showing method of installing water level gauge and weir on small streams.

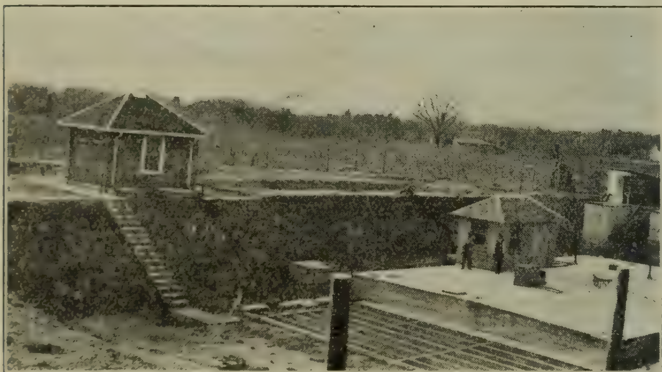

PLATE J.

Septic tank and mixing chambers at El Dorado, Kan., showing chemical house and sludge bed.

PLATE K.

Disposal plant at Independence, Kan., showing septic tank and contact beds.

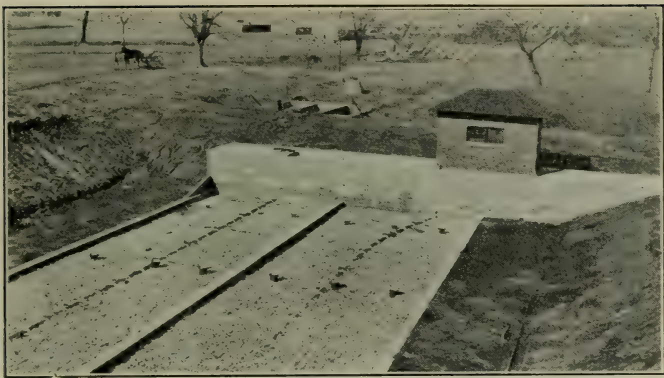

PLATE L.
Disposal plant at Burlingame, Kan., showing Imhoff tank and contact beds.

PLATE M.
Disposal plant at Osage City, Kan., showing septic tank and contact beds.

PLATE N.
Disposal plant at Cherryvale, Kan., showing contact beds and control houses.

PLATE O.
Contact beds at Girard, Kan., showing effect of lack of care.

PLATE P.
Disposal plant at the State Tubercular Sanatorium at Norton, Kan., showing sand filters and distributors.

PLATE Q.
Typical arrangement of nozzles and distributing pipes in sprinkling filters.

PLATE R.
Sludge digestion tanks, with sludge-drying beds.

PLATE S.
Disposal plant at Cherryvale, Kan., showing a very poorly constructed and ineffective sludge-drying bed.

PLATE T.
Disposal plant at Fort Scott, Kan., showing growth of weeds on poorly cared-for sludge bed.

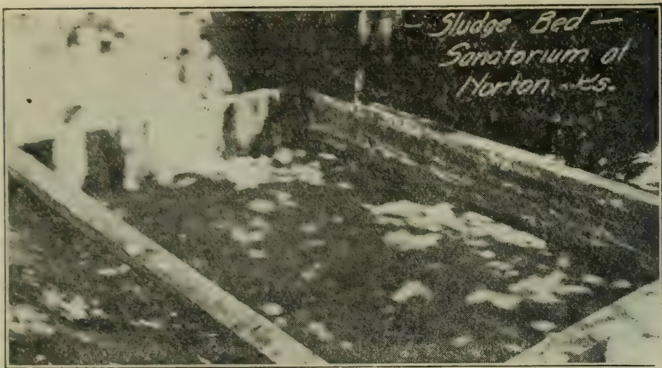

PLATE U.

Well-made sludge bed at State Tubercular Sanatorium, at Norton, Kan. Note clean sand, concrete sides and flood-protection manhole.

PLATE V.

Sludge drying on sludge bed at Caldwell, Kan. Note man shoveling dried sludge.

PLATE W.

Poorly drained sludge bed at Sabetha, Kan.

APPENDIX.

TABLE Nos. 1.—Results of chemical tests, raw sewage, Burlingame.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry season:												
2-15-15.....	12	....	2.0	656	88	....	70	614	120	734	14,900	....
2-17-15.....	12	....	3.0	520	96	....	120	646	118	764	14,810	....
2-18-15.....	13	....	2.0	860	....	....	180	....	....	....	12,760	....
2-18-15.....	12	....	4.0	330	59	....	35	678	170	848	17,230	....
Average....	12	....	2.7	591	81	....	108	646	136	782	14,925	15
Average season:												
12-18-15.....	12	....	5.0	442	70	24	25	840	70	910	....	....
12-13-15.....	12	....	4.0	313	64	24	25	842	110	952	30,000	....
12-14-15.....	12	....	3.0	290	64	16	30	764	112	876	37,100	....
12-15-15.....	12	....	4.0	292	70	18	35	912	52	964	40,500	....
12-16-15.....	12	....	4.5	266	70	18	25	760	110	870	32,600	....
12-18-15.....	12	....	4.1	131	68	28	25	790	74	864	36,800	....
12-19-15.....	12	....	4.0	221	76	24	25	930	120	1,050	29,700	....
12-20-15.....	11	....	3.0	407	70	24	35	1,090	184	1,274	31,200	....
1- 5-16.....	6	....	6.0	262	82	36	30	822	80	902	....	....
1- 6-16.....	6	....	4.0	536	82	36	35	844	156	1,000	....	....
1- 7-16.....	6	....	4.5	494	78	32	35	828	110	838	....	....
Average.....	....	....	4.5	332	72	25	28	855	106	961	35,400	6
Wet season:												
2-23-15.....	11	....	6.0	210	82	....	70	812	554	1,366	46,680	Stable for 10 days.
2-24-15.....	10	....	5.0	174	114	....	7	1,250	136	1,386	104,900	
2-25-15.....	10	....	8.0	194	96	....	14	1,126	56	1,182	119,200	
2-26-16.....	11	....	8.0	214	100	....	70	1,130	20	1,150	72,480	
Average....	....	....	7.0	198	98	....	48	1,079	191	1,270	86,000	....

TABLE No. 2.—Results of chemical tests—Imhoff tank effluent, Burlingame.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry season:												
2-16-15	12	0	0	656	88	28	60	660	72	732	14,900	....
2-17-15	12	0	0	565	82	....	60	730	110	840	14,810	....
2-18-15	12	0	0	514	82	80	80	666	80	746	12,760	....
2-19-15	12	0	0	578	76	40	60	594	76	670	17,230	....
Average	....	....	0	578	8	46	65	662	84	746	14,925	13
Average season:												
12-12-15	12	30	1.0	125	66	28	15	754	36	790	....	....
12-13-15	12	21	.8	139	66	20	20	810	20	830	30,000	....
12-14-15	11	21	0	120	66	12	25	798	30	828	37,100	....
12-15-15	11	21	0	122	68	16	30	830	30	860	40,500	....
12-16-15	12	21	0	98	66	16	20	770	70	840	32,600	....
12-18-15	8	15	0	124	70	28	20	748	60	808	36,800	....
12-19-15	8	15	0	162	70	18	20	836	20	856	29,700	....
12-20-15	8	15	0	131	76	24	30	858	16	874	31,200	....
1- 5-16	6	15	0	131	78	32	25	780	76	856	....	....
1- 7-16	6	15	0	144	78	32	30	836	20	856	....	....
Average	....	21	....	125	70	23	24	792	41	833	35,400	9
Wet season:												
2-22-15	12	90+	....	210	96	36	....	1,030	46	1,076	....	Stable.
2-23-15	12	90+	3.0	202	94	10	40	1,076	68	1,144	46,680	
2-24-15	10	90+	4.0	216	98	....	....	1,210	20	1,230	104,900	
2-25-15	9	90+	7.0	196	98	16	17	1,190	46	1,236	119,200	
2-26-15	10	90+	10.0	218	103	....	14	1,182	30	1,212	72,480	
Average	....	....	6.0	208	98	13	24	1,137	43	1,180	86,000	....

TABLE No. 3.—Results of chemical tests, contact-bed effluent, Burlingame.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.									Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.					
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.			
Dry season:													
2-16-15	11.5	....	1.0	276	64	8	35	642	192	734		....	....
2-19-15	11.5	....	2.0	432	80	72	80	654	40	694		....	....
2-22-15	12.0	....	1.0	252	....	....	....	924	40	964		....	....
Average	....	....	1.5	320	72	40	57	740	57	797		14,925	10
Average season:													
12-12-15	12	94	6.5	....	68	14	20	858	66	924		....	....
12-13-15	12	96	8.2	114	72	18	20	810	30	840		....	....
12-14-15	11	75	6.0	102	64	12	20	810	26	836		....	....
12-15-15	11	95	4.8	90	64	14	25	790	30	820		....	....
12-16-15	12	90	4.6	70	68	12	20	778	76	854		....	....
12-18-15	9	95	6.8	72	68	20	20	678	48	726		....	....
12-19-15	9	90	5.5	64	66	12	17	760	30	790		....	....
2-20-15	8	96	5.0	100	72	16	25	828	12	840		....	....
1-5-16	5	95	9.2	70	68	20	20	728	42	770		....	....
1-6-16	6	95	5.9	136	78	24	25	786	50	836		....	....
1-7-16	7	95	6.5	106	74	28	20	844	18	862		....	....
Average	....	....	6.0	85.4	69	17	21	789	38	827		35,400	6
Wet season:													
2-23-15	9	99	4.0	208	128	10	40	1,228	74	1,302		....	....
2-24-15	9	99	4.0	220	94	....	....	1,156	108	1,264		....	....
2-25-15	9	99	6.5	210	100	16	25	1,222	18	1,240		....	....
2-26-15	10	99	6.5	200	94	17	28	1,202	68	1,270		....	....
Average	....	99	[illegible]	210	104	15	31	1,204	67	1,271		86,000	0

TABLE No. 5.—Results of chemical tests—raw sewage, Osage City.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
11-10-14	21	0	0	456	71	12	70	672	40	712	....	....
11-11-14	21	0	0	448	76	....	50	750	102	852	....	....
11-12-14	20	0	0	323	82	8	35	784	56	840	28,000	....
11-13-14	20	0	0	490	....	....	....	726	70	796	25,150	....
11-17-14	19	0	0	433	....	14	100	676	70	746	28,700	....
11-18-14	99	0	0	365	....	14	35	490	20	510	30,500	....
11-19-14	19	0	0	352	80	....	....	....	....	....	....	....
11-20-14	19	0	0	326	76	20	100	634	40	674	....	....
Average	....	0	0	399	73	13	55	676	57	733	28,090	....

TABLE No. 6.—Results of chemical tests—contact bed effluent, Osage City.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
11-10-14	20	*15	0.4	249	111	10	50	754	62	816	....	....
11-11-14	17	37	0.5	235	88	12	35	836	142	978	....	....
11-12-14	19	37	0.5	241	82	8	35	784	56	840	28,000	....
11-13-14	19	37	0.8	149	....	14	....	1,004	18	1,022	25,150	....
11-17-14	16	25	1.0	282	....	12	85	1,022	50	1,072	28,700	....
11-18-14	16	37	0	482	76	14	35	700	60	760	30,500	....
11-19-14	16	25	0	402	74	14	30	644	48	692	....	....
11-20-14	16	15	0	356	80	20	100	620	40	660	....	....
Average	....	*28	0.4	299	85	13	55	801	59	860	28,090	....

*In 1 to 10 dilutions in water.

TABLE No. 7.—Results of chemical tests—raw sewage, Newton.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry season.												
11-24-14	19	....	0	535	79	20	....	628	172	800	....	....
11-25-14	19	....	0	550	75	14	17	562	408	970	....	....
11-26-14	19	....	0	301	162	14	20	680	346	1,026	155,000	....
11-27-14	19	....	0	498	73	20	40	672	202	874	135,000	....
11-30-14	19	....	0	571	73	24	484	232	716	127,000	....	....
12- 1-14	18	....	0	705	86	14	....	590	452	1,042	135,000	....
12- 2-14	19	....	0	873	99	....	....	620	402	1,022	165,000	....
12- 3-14	19	....	0	699	100	24	35	614	268	882	172,000	....
12- 4-14	19	....	0	680	104	24	....	600	292	892	170,000	....
Average	....	....	....	601	94	19	32	603	309	912	148,515	33
Wet season:												
3- 4-15	9	....	7.0	350	156	....	35	1,476	180	1,656	....	....
3- 5-15	9	....	7.0	494	140	....	14	1,268	196	1,464	....	....
3- 8-15	8	....	6.0	480	170	....	35	1,450	158	1,608	....	....
3-15-15	7	....	7.0	495	136	....	40	1,250	156	1,406	....	....
3-16-15	9	....	6.0	580	132	....	40	1,190	192	1,382	365,000	....
3-17-15	11	....	8.0	547	122	....	40	1,166	118	1,284	405,000	....
3-18-15	11	....	9.0	396	147	....	17	1,242	90	1,332	365,000	....
3-19-15	11	....	8.0	292	134	....	25	1,212	82	1,294	365,000	....
Average	....	....	7.3	454	142	....	31	1,279	146	1,425	353,554	14

TABLE No. 8.—Results of chemical tests—septic-tank effluent, Newton.

Date.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry season:												
11-24-14	18	....	0	374	89	....	10	664	70	734	....	....
11-25-14	18	....	0	332	76	....	20	552	156	708	....	....
11-26-14	18	....	0	329	104	....	14	642	136	778	155,000	....
11-27-14	18	....	0	308	104	....	17	690	50	740	135,000	....
11-30-14	18	....	0	388	111	....	17	586	146	732	127,000	....
12- 1-14	18	....	0	331	78	....	7	422	294	716	135,000	....
12- 2-14	18	....	0	433	92	....	10	590	370	960	165,000	....
12- 3-14	18	....	0	313	90	....	14	572	370	940	172,000	....
12- 4-14	18	....	0	282	69	....	25	514	106	620	170,000	....
Average	....	....	0	343	90	....	15	603	188	791	148,515	37.7
Wet season.												
3- 4-15	10	....	5.0	324	148	....	36	1,374	84	1,458	....	....
3- 5-15	9	....	6.0	446	140	....	70	1,306	118	1,424	....	....
3- 8-15	8	....	4.0	450	156	....	40	1,402	110	1,512	....	....
3-15-15	10	....	4.5	334	142	....	30	1,288	30	1,318	....	....
3-16-15	11	....	6.0	348	145	....	40	1,248	90	1,338	365,000	....
3-17-15	11	....	5.5	335	122	....	80	1,186	118	1,304	305,000	....
3-18-15	11	....	5.5	325	142	....	48	1,202	96	1,298	365,000	....
3-19-15	11	....	5.5	250	132	....	45	1,152	70	1,222	365,000	....
Average	....	....	5.0	351	141	....	48	1,291	103	1,394	353,554	15

TABLE No. 9.—Results of chemical tests—raw sewage, Winfield.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.									Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
12- 8-14	22	0	4.0	1,208	71	12	25	864	216	1,080	.....	.....
12- 9-14	23	0	4.5	1,220	.....	.....	100	1,546	460	2,006	.....	.....
12-10-14	23	0	4.0	1,517	190	24	85	868	48	916	.....	.....
12-11-14	23	0	4.5	1,030	.....	35	.....	952	238	1,190	.....	.....
12-14-14	23	0	4.8	976	.....	28	35	608	334	942	.....	.....
12-15-14	23	0	5.0	627	150	8	35	466	186	652	.....	.....
12-16-14	24	0	6.0	1,472	.....	.....	.....	.....	.....	.....	.....	.....
12-17-14	24	0	5.0	1,370	105	5	35	598	376	974	.....	.....
12-18-14	24	0	3.5	1,220	252	8	50	924	466	1,390	.....	.....
3-24-15	20	0	5.0	1,523	160	52	60	588	212	800	.....	.....
3-25-15	20	0	4.8	1,500	256	48	50	640	272	912	.....	.....
3-26-15	18	0	5.0	.....	41	34	40	258	92	550	.....	.....
3-29-15	18	0	5.5	.....	41	28	25	746	208	954	.....	.....
3-30-15	15	0	4.5	.....	42	4	25	480	86	566	.....	.....
3-31-15	15	0	4.0	1,310	43	4	35	492	62	554	.....	.....
4- 1-15	15	0	3.0	1,570	140	5	52	548	454	1,002	.....	.....
4- 2-15	15	0	4.5	1,640	.....	.....	.....	1,050	812	1,862	.....	.....
9- 7-15	.....	0	.....	.....	108	28	30	1,470	300	1,770	.....	.....
9- 8-15	.....	0	.....	.....	80	7	25	1,282	358	1,640	.....	.....
9- 9-15	.....	0	.....	.....	60	10	25	670	130	800	.....	.....
9-14-15	.....	0	.....	.....	60	28	120	600	150	750	.....	.....
9-15-15	.....	0	.....	.....	60	64	140	660	130	790	.....	.....
9-16-15		0	.....	.....	108	64	200	860	210	1,070	.....	.....
9-17-15	.....	0	.....	.....	84	36	70	840	190	1,030	.....	.....
Average	.....	0	4.0	1,490	108	25	55	825	260	1,085	32,450	56

TABLE No. 10.—Results of chemical tests—Imhoff tank effluent, Winfield.

Date.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
3-23-15	12	0	0	910	.....	112	180	562	232	794	.....	.....
3-24-15	12	0	0	1,370	160	60	120	576	202	778	.....	.....
3-25-15	12	0	0	940	256	48	50	640	272	912	.....	.....
3-26-15	10	0	0	.....	.....	48	50	526	142	666	.....	.....
3-29-15	12	0	0	.....	.....	.....	.....	806	120	926	.....	.....
3-30-15	10	0	0	.....	62	.....	120	636	118	754	.....	.....
3-31-15	11	0	0	980	56	.....	.....	638	218	856	.....	.....
4- 1-15	11	0	0	833	.....	.....	48	572	174	746	.....	.....
4- 2-15	13	0	0	880	.....	.....	.....	600	174	774	.....	.....
3- 7-15	.....	0	0	.....	74	56	30	910	110	1,020	.....	.....
3- 8-16	.....	0	0	.....	86	56	30	960	114	1,074	.....	.....
3-13-16	.....	0	0	.....	114	40	100	924	160	1,084	.....	.....
3-15-16	20	0	0	990	100	48	35	878	114	992	.....	.....
3-17-16	22	0	0	685	80	28	35	690	40	730	.....	.....
3-20-16	20	0	0	953	80	36	45	902	114	1,016	.....	.....
3-21-16	20	0	0	959	76	28	40	810	190	1,000	.....	.....
3-22-16	20	0	0	1,113	78	24	35	665	30	695	.....	.....
3-23-16	20	0	0	770	72	40	40	730	100	830	.....	.....
3-24-16	20	0	0	1,040	60	32	40	826	80	906	.....	.....
4- 4-16	20	0	0	926	68	24	30	628	100	728	.....	.....
4- 5-16	20	0	0	1,003	60	28	30	702	190	892	.....	.....
4- 6-16	20	0	0	800	68	32	50	736	120	856	.....	.....
Average	.....	0	0	946	91	42	57	720	145	865	32,450	79

TABLE No. 11.—Results of chemical tests—contact bed effluent, Winfield.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
3-23-15	8	25	Trace.	638	45	7	....	552	142	694	....	....
3-24-15	7	11	Trace.	790	56	4	60	626	100	726	....	....
3-25-15	9	11	Trace.	750	56	25	54	628	170	798	....	....
3-26-15	8	11	Trace.	....	46	....	30	598	80	678	....	....
3-29-15	9	11	Trace.	....	56	14	29	342	276	618	....	....
3-30-15	5	11	Trace.	....	64	64	100	532	134	666	....	....
3-31-15	5	11	Trace.	765	60	....	80	590	416	1,006	....	....
4- 1-15	9	11	Trace.	710	56	....	120	552	78	630	....	....
4- 2-15	7	11	Trace.	806	64	96	25	608	138	746	....	....
3- 7-16	....	11	Trace.	....	64	36	35	664	146	810	....	....
3- 8-16	....	11	Trace.	....	68	64	40	874	50	924	....	....
3-11-16	....	11	Trace.	....	68	68	45	670	64	734	....	....
3-15-16	....	11	Trace.	....	102	68	35	784	86	870	....	....
3-15-16	20	11	Trace.	680	90	102	30	778	90	868	....	....
3-16-16	20	11	Trace.	530	98	90	35	782	118	900	....	....
3-17-16	20	11	Trace.	685	84	98	40	....	....	....	....	....
3-20-16	18	11	Trace.	693	74	84	40	724	84	808	....	....
3-21-16	20	11	Trace.	456	70	74	30	628	100	728	....	....
3-22-15	18	11	Trace.	480	70	70	35	676	22	698	....	....
3-23-15	20	11	Trace.	636	78	70	40	722	82	804	....	....
3-24-15	20	11	Trace.	606	84	78	30	780	60	840	....	....
4- 4-15	20	11	Trace.	476	66	84	30	584	52	636	....	....
4- 5-15	20	11	Trace.	500	58	66	35	600	70	670	....	....
4- 6-15	20	11	Trace.	....	56	58	35	690	70	760	....	....
Average	....	11	Trace.	637	68	33	45	650	103	753	32,450	40

TABLE No. 12.—Results of chemical tests—sand-filter effluent, Winfield.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
12- 8-14	13	37	4.5	86	....	7	10	488	44	532	....	....
12- 9-14	13	60	4.5	77	....	9	50	574	42	616	....	....
12-10-14	12	50	4.0	57	....	12	35	550	60	610	....	....
12-11-14	13	50	4.5	69	....	14	25	528	68	596	....	....
12-12-14	11	37	4.0	128	....	12	70	516	32	548	....	....
12-15-14	12	90	4.0	130	....	12	70	570	70	640	....	....
12-16-14	12	37	4.5	137	....	....	50	496	54	550	....	....
12-17-14	12	37	4.5	117	....	24	50	476	60	536	....	....
12-18-14	12	37	4.0	91	....	....	50	498	70	568	....	....
Average	....	48	4.3	99	....	12	45	521	90	611	32,450	30

TABLE No. 13.—Results of chemical tests—trickling filter effluent, Winfield.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.									Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.					
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.			
3- 7-16	....	....	....	....	74	32	30	758	74	832		....	....
3- 8-16	....	....	....	....	70	32	35	700	62	762		....	....
3-11-16	....	....	....	....	66	32	35	678	74	752		....	....
3-13-16	....	....	....	....	100	40	40	764	100	864		....	....
3-15-16	18	15	3.7	553	86	30	20	926	64	990		....	....
3-16-16	16	20	4.1	480	80	20	30	744	50	794		....	....
3-17-16	19	15	4.0	490	126	36	35	....	....	....		....	....
3-20-16	20	15	3.1	546	72	20	40	728	80	808		....	....
3-21-16	20	15	4.6	390	70	36	30	654	136	790		....	....
3-22-16	21	10	3.6	403	74	20	35	740	60	800		....	....
3-23-16	20	15	3.2	436	68	10	40	710	80	790		....	....
3-24-16	20	20	4.2	566	80	24	25	720	140	860		....	....
4- 4-16	20	15	5.7	426	64	24	35	564	100	664		....	....
4- 5-16	20	15	6.1	340	56	16	30	540	140	680		....	....
4- 6-16	....	15	5.1	....	56	24	35	676	94	770		....	....
Average	....	15	4.3	463	76	26	33	710	100	810		32,450	34

TABLE No. 14.—Results of chemical tests—raw sewage, Girard.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
1- 6-15	15	....	0	542	230	16	35	1,162	476	1,638	120,600	....
1- 7-15	15	....	1.0	305	390	....	18	1,436	118	1,554	77,400	....
1- 8-15	14	....	2.0	282	410	25	25	1,494	120	1,614	64,700	....
1-11-15	14	....	5.0	330	330	6	10	1,378	154	1,532	63,100	....
1-12-15	13	....	4.0	252	250	....	18	1,486	88	1,574	132,600	....
1-13-15	14	....	4.6	280	400	....	43	1,484	212	1,696	82,500	....
1-14-15	14	....	3.0	435	420	....	50	1,580	174	1,754	75,200	....
Average	....	....	3.0	358	359	15	28	1,432	191	1,623	88,010	22

TABLE No. 15.—Results of chemical tests—effluent, Girard.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
1- 6-15	11	0	0	452	400	32	3.50	1,390	320	1,710	120,600	....
1- 7-15	10	0	0	434	387	....	5	1,418	96	1,514	77,400	....
1- 8-15	12	0	0	341	425	3	5	1,530	70	1,600	64,700	....
1-11-15	15	0	0	318	320	....	8	1,492	44	1,536	63,100	....
1-12-15	15	0	0	250	350	....	10	1,354	106	1,460	132,600	....
1-13-15	13	0	0	348	385	....	25	1,220	338	1,558	82,500	....
1-14-15	14	0	0	553	410	....	18	1,528	218	1,746	75,200	....
Average	....	....	0	385	383	17	11	1,419	170	1,589	88,010	31

TABLE No. 16.—Results of chemical tests—raw sewage, Independence.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.									Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.					
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.			
1-19-15	10	90+	6.1	128	75	16	....	656	268	924		200,000	....
1-20-15	10	90+	6.4	167	124	7	25	620	46	666		199,500	....
1-21-15	8	90+	6.4	143	72	6	25	....	....	634		200,400	....
1-22-15	8	90+	6.0	133	58	25	25	....	....	580		225,000	....
1-26-15	9	90+	6.0	188	68	4	25	526	84	610		285,900	....
1-27-15	9	90+	6.0	138	72	16	50	570	10	580		296,500	....
1-28-15	9	90+	6.5	186	60	20	25	460	40	500		279,200	....
1-29-15	10	90+	7.0	233	74	24	25	550	30	580		280,000	....
4- 7-15	9	90+	3.2	294	95	20	40	940	70	1,010		221,000	....
4-12-15	11	90+	4.6	105	87	5	17	980	40	1,020		375,000	....
4-13-15	11	90+	4.5	165	107	16	....	850	240	1,090		330,000	....
4-14-15	11	90+	4.5	200	96	20	....	1,010	60	1,070		289,000	....
4-15-15	11	90+	5.5	150	82	7	17	910	30	940		263,000	....
4-16-15	11	90+	5.0	200	101	17	20	930	50	980		255,900	
Average	....	90+	5.6	174	85	15	26	750	81	831		264,310	8

TABLE No. 17.—Results of chemical tests—septic-tank effluent, Independence.

Date.	Temperature, degrees C.	Stability figure.	Parts per million. Oxygen. Dissolved.	Oxygen. Consumed in 5 minutes at 100° C.	Chlorine.	Nitrogen. Free ammonia.	Nitrogen. Total organic.	Solids. Dissolved.	Solids. Suspended.	Solids. Total.	Sewage flow in gallons per day.	Dilution required volumes.
1-26-15	7	90+	5.8	127	72	11	35	536	44	580	....	....
1-27-15	6	90+	5.5	133	78	13	25	562	210	772	....	....
1-28-15	7	90+	6.9	131	56	11	25	494	16	510	....	....
1-29-15	8	90+	7.5	119	58	24	25	....	....	....	....	....
4- 7-15	9	90+	3.0	256	105	28	40	990	40	1,030	....	....
4-12-15	12	90+	5.0	124	92	3	17	950	30	980	....	....
4-13-15	11	90+	4.5	134	111	4	....	1,010	30	1,100	....	....
4-14-15	12	90+	4.5	152	113	28	....	1,010	30	,040	....	....
4-15-15	11	90+	4.8	188	106	14	14	....	....	....	....	....
4-16-15	11	90+	4.0	111	110	30	30	990	50	1,040	....	....
Average	....	90+	5.2	138	89	17	26	819	57	876	264,310	11

TABLE No. 18.—Results of chemical tests—contact-bed effluent, Independence.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
1-19-15	7	90+	8.0	59	85	....	....	....	....	....	....	....
1-20-15	6	90+	7.5	114	72	1	....	644	22	666	....	....
1-21-15	5	90+	8.9	105	25	3	18	....	....	....	....	....
1-22-15	4	90+	8.6	82	66	2	18	....	....	....	....	....
1-26-15	5	90+	7.1	91	68	11	5	532	76	608	....	....
1-27-15	5	90+	9.2	56	74	4	20	....	....	....	....	....
1-28-15	5	90+	10.0	53	58	1	20	538	6	544	....	....
1-29-15	5	90+	10.0	53	58	5	10	546	14	560	....	....
4- 7-15	9	90+	6.0	137	118	14	5	1,060	0	1,060	....	....
4-12-15	10	90+	6.0	32	85	4	14	970	60	1,030	....	....
4-13-15	11	90+	6.2	30	92	4	17	1,060	0	1,060	....	....
4-14-15	10	90+	7.0	68	107	20	14	1,040	0	1,040	....	....
4-15-15	11	90+	6.5	52	103	7	25	1,040	20	1,060	....	....
4-16-15	11	90+	6.0	31	101	17	17	930	50	980	....	....
Average	....	90+	7.7	69	83	7	14	816	23	839	264,310	4.5

TABLE No. 19.—Results of chemical tests—raw sewage, Cherryvale.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry season:												
2- 3-15	12	....	....	214	86	20	27	690	120	810	....	....
2- 4-15	12	....	5.0	232	68	8	25	718	96	814	....	....
2- 5-15	11	50	....	214	98	18	20	708	70	778	....	....
2- 9-15	11	37	5.0	273	160	14	14	778	122	900	....	....
2-11-15	12	37	4.0	390	100	8	25	682	116	798	....	....
2-12-15	12	37	4.5	345	77	16	20	576	100	676	....	....
Average	....	40	4.5	278	97	14	22	693	104	797	220,700	12
Wet season:												
4-20-15	11	90	5.8	215	83	16	20	870	10	880	....	....
4-21-15	11	90	6.0	186	110	11	14	960	20	980	....	....
4-22-15	11	75	5.0	203	....	5	20	670	420	1,090	....	....
4-23-15	11	75	5.0	165	57	14	25	890	20	910	....	....
4-28-15	12	90	4.0	148	70	14	14	1,000	180	1,080	....	....
4-29-15	12	90	5.5	159	74	5	10	420	2,630	3,050	....	....
4-30-15	12	90	6.0	166	38	....	....	....	....	....	....	....
1-25-16	8	95	....	122	70	6	14	914	48	962	....	....
1-26-16	8	98	....	139	72	6	17	952	32	984	....	....
1-28-16	6	99	....	144	66	3.4	14	874	20	894	....	....
1-29-16	6	99	....	77	72	3.4	12	906	12	918	....	....
1-31-16	5	90	....	153	64	6	17	848	....	....	....	....
2- 1-16	7	85	8.0	77	64	3.4	7	848	72	920	....	....
2- 4-16	5	75	7.0	151	74	10	17	930	30	960	....	....
Average	....	90	6	148	70	8	15	855	280	1,135	741,000	5

TABLE NO. 20.—Results of chemical tests—septic-tank effluent, Cherryvale.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry season:												
2- 3-15	11	90	....	....	88	16	16	696	22	718	....	....
2- 4-15	11	75	7.0	220	68	8	25	718	96	814	....	....
2- 5-15	10	90	4.0	182	84	14	28	658	50	708	....	....
2- 9-15	11	75	4.0	316	152	17	....	778	106	884	....	....
2-11-15	12	50	3.5	453	84	12	14	862	170	1,032	....	....
2-12-15	12	50	....	310	88	16	17	588	42	630	....	....
Average	....	75	4.5	290	94	14	20	716	81	797	220,700	12.5
Wet season:												
4-20-15	12	75	6.0	197	90	20	24	850	20	870	....	....
4-21-15	12	90	6.5	96	113	11	17	950	30	980	....	....
4-22-15	12	90	5.5	97	....	....	....	850	10	860	....	....
4-23-15	12	75	5.2	102	73	4	17	920	140	1,060	....	....
4-28-15	12	90	6.0	95	71	2	10	950	20	970	....	....
4-29-15	12	90	5.8	113	79	2	10	....	....	....	....	....
4-30-15	12	90	6.0	92	48	5	10	900	54	954	....	....
1-25-16	8	90	....	81	70	6	14	976	30	1,006	....	....
1-26-16	8	90	....	75	66	5	14	860	26	886	....	....
1-28-16	6	90	....	79	70	4	12	918	50	968	....	....
1-29-16	6	90	....	76	60	4	13	888	12	900	....	....
1-31-16	5	90	....	69	70	6	17	848	16	864	....	....
2- 1-16	7	90	....	99	64	3.4	7	896	72	968	....	....
2- 4-16	5	90	....	91	72	9	14	730	40	770	....	....
Average	....	90	55	97	72	6	14	885	41	926	741,000	4

TABLE No. 21. Results of chemical tests—contact-bed effluent, Cherryvale.

Date.	Temperature, degrees C.	Stability figure.	Parts per million.									Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Dry weather:												
2- 3-15	11	75	10	....	80	16	20	696	70	766	268,200	....
2- 4-15	11	90	11	193	76	13	17	672	46	718	221,600	....
2- 5-15	10	75	8	138	90	8	10	660	76	736	228,300	....
2- 9-15	11	75	6	220	78	25	25	768	54	822	204,200	....
2-11-15	12	90	6	128	94	8	14	624	48	672	181,100	....
2-12-15	12	75	7	106	78	11	11	592	38	630	....	....
Average	....	80	8	157	83	13	16	671	55	726	220,700	7
Wet weather:												
4-20-15	11	90+	5.5	91	88	5	25	900	30	930	350,000	....
4-21-15	12	84+	4.0	31	90	2	10	920	10	930	306,900	....
4-22-15	12	90+	3.5	27	....	....	....	....	....	....	389,100	....
4-23-15	12	90+	7.0	46	71	28	20	900	50	950	682,000	....
4-28-15	12	90+	4.5	45	70	3	25	910	0	910	719,000	....
4-29-15	12	90+	5.0	49	79	2	14	940	20	960	618,000	....
4-30-15	12	90+	3.0	35	76	5	7	940	50	990	....	....
1-25-15	....	90+	....	74	68	5	12	890	30	920	....	....
1-26-15	10	99	....	76	66	3	14	944	16	960	755,000	....
1-28-15	10	96	....	54	64	3	14	848	50	898	860,000	....
1-29-15	6	99	....	42	63	3	13	890	9	899	789,000	....
1-31-16	5	75	....	56	64	5	10	824	16	840	757,000	....
2- 1-16	6	99	....	58	64	3	7	830	30	860	407,000	....
2- 4-16	6	90	....	72	72	5	10	868	12	880	358,000	....
Average	....	90+	4.6	54	72	6	14	892	31	923	741,000	1

TABLE No. 22.—Results of chemical tests—raw sewage, El Dorado.

DATE.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
10-11-15	18	0	*	210	70	48	50	674	86	760	....	....
10-12-15	18	0	*	355	66	40	70	644	60	704	....	....
10-13-15	18	0	*	557	80	24	70	616	30	646	....	....
10-15-15	18	0	*	480	68	36	70	666	124	790	....	....
10-18-15	17	0	*	785	82	80	120	754	260	1,014	....	....
10-20-15	17	0	*	602	76	32	80	604	116	720	....	....
10-22-15	17	0	*	620	98	40	70	640	114	754	....	....
10-23-15	17	0	*	711	98	40	200	856	110	966	....	....
10-24-15	17	0	*	685	72	64	100	700	36	736	....	....
10-26-15	17	0	*	586	136	28	160	796	14	810	....	....
11-12-15	17	0	*	612	64	24	60	640	150	790	....	....
11-13-15	16.5	0	*	578	70	24	70	636	114	750	....	....
11-15-15	16	0	*	804	78	20	120	790	250	1,040	....	....
11-16-15	16	0	*	590	86	16	70	688	92	780	....	....
11-17-15	16	0	*	594	72	64	90	704	136	840	....	....
11-18-15	16	0	*	585	76	32	70	686	130	816	....	....
11-24-15	16	0	*	692	82	24	90	844	66	910	....	....
11-25-15	16	0	*	586	80	24	80	726	74	900	....	....
11-26-15	16	0	*	596	80	24	60	740	60	800	....	....
12-2-15	16	0	*	502	86	32	80	698	120	818	....	....
Average	....	0	*	590	81	36	89	725	107	832	165,078	....

*Dissolved oxygen present in early morning only.

TABLE No. 23.—Results of chemical tests—septic-tank effluent, El Dorado Plant.

Date.	Temperature, degrees C.	Stability figure.	Parts per million. Oxygen. Dissolved.	Oxygen. Consumed in 5 minutes at 100° C.	Chlorine.	Nitrogen. Free ammonia.	Nitrogen. Total organic.	Solids. Dissolved.	Solids. Suspended.	Solids. Total.	Sewage flow in gallons per day.	Dilution required volumes.
10-13-15	18		0	350	70	32	50	580	36	616		
10-14-15	18		0	360	70	48	80	650	14	654		
10-15-15	17		0	445	72	28	70	614	80	694		
10-18-15	18		0	447	74	28	80	650	90	740		
10-20-15	17		0	501	92	20	80	696	130	826		
10-23-15	17		0	390	98	24	100	686	20	706		
10-24-15	175		0	535	92	70	100	706	20	726		
10-26-15	17		0	403	136	28	160	696	14	710		
10-27-15	17		0	425	86	32	60	690	30	720		
10-28-15	17		0	325	74	48	50	634	50	684		
10-29-15			0		86	20	50	586	44	630		
11- 2-15	16.5			326	64	24	40	616	36	652		
11- 3-15	17		0	302	64	24	40	602	28	630		
11- 4-15	17		0	312	78	24	40	626	44	670		
11- 5-15					66	18	50	608	36	644		
11- 6-15					70	32	50	654	30	684		
11- 8-15					82	20	60	610	80	690		
11-12-15	17		0	318	62	20	50	620	16	636		
11-13-15	17		0	303	66	20	50	636	30	666		
11-15-15	17		0	297	74	18	50	644	30	674		
11-16-15	16		0	313	74	16	50	580	18	598		
11-17-15	16		0	320	64	24	60	620	26	646		
11-18-15	16		0	313	68	20	60	640	70	710		
11-24-15	16		0	345	86	12	60	680	10	690		
11-25-15	16				82	14	50	684	10	694		
11-26-15	16		0	320	90	16	40	702	12	714		
11-29-15	15				84	18	50	700	34	734		
11-30-15	16			381	82	16	50	764	40	804		
12- 1-15	16				74	20	50	680	20	700		
12- 2-15	16			293	84	20	50	640	50	690		
Average			0	362	77	27.6	61	649	39	688	165,078	

TABLE No. 24.—Results of chemical tests—septic-tank effluent which has been sterilized and settled, El Dorado.

Date.	Temperature, degrees C.	Stability figure.	Parts per million.								Sewage flow in gallons per day.	Dilution required volumes.
			Oxygen.		Chlorine.	Nitrogen.		Solids.				
			Dissolved.	Consumed in 5 minutes at 100° C.		Free ammonia.	Total organic.	Dissolved.	Suspended.	Total.		
Two-hour settling period:												
10-11-15	18	0	0	184	....	56	60	604	40	644	....	....
10-12-15	18	0	0	162	....	48	50	400	20	420	....	....
10-13-15	18	0	0	224	....	20	80	836	190	1,026	....	....
10-14-15	18	0	0	306	....	56	60	764	6	770	....	....
10-18-15	17	0	0	297	....	40	100	644	46	1,090	....	....
10-20-15	17	0	0	385	....	36	70	676	70	746	....	....
10-72-15	17	0	0	361	....	40	55	606	70	676	....	....
10-23-15	17	0	0	380	....	46	140	702	66	768	....	....
10-24-15	17	0	0	419	....	72	90	710	4	714	....	....
10-26-15	17	0	0	369	....	64	140	614	26	640	....	....
11- 3-15	17	0	0	311	....	24	40	624	28	652	....	....
11- 4-15	17	0	0	323	....	24	40	694	24	718	....	....
11- 5-15	17	0	0	340	....	14	50	566	46	612	....	....
11- 6-15	17	0	0	335	....	24	50	620	30	650	....	....
11- 7-15	17	0	0	326	....	16	50	650	20	670	....	....
Average	....	0	0	314	....	26	47	647	45	692	165,078	....
One-hour settling period:												
10-27-15	17	0	0	375	....	32	60	700	30	730	....	....
10-28-15	17	0	0	346	....	20	50	638	48	686	....	....
10-29-15	17	0	0	320	....	28	40	650	34	684	....	....
11- 2-15	17	0	0	314	....	24	40	656	24	670	....	....
Average	....	0	0	340	....	36	47	656	34	690	165,078	....

TABLE No. 25. Tabulation of Bacterial Results at El Dorado, Kan.

DATE.	Hour.	Raw sewage.		Septic tank effluent.		Chlorine. p. p. m.	Treated effluent.		Remarks.
		Total.	Red colonies.	Total.	Red colonies.		Total.	Red colonies.	
10–12	7 a. m.	50,000	400	...	...	10	800	100	Full set of channels, 2 hours.
10–12	10 a. m.	210,000	40,000	...	...	10	600	0	Full set of channels, 2 hours.
10–12	2 p. m.	180,000	60,000	...	...	10	...	...	Full set of channels, 2 hours.
10–12	5 p. m.	10,000	3,000	...	...	10	500	0	Full set of channels, 2 hours.
10–13	7 a. m.	20,000	10,000	...	...	10	110	0	Full set of channels, 2 hours.
10–13	10 a. m.	200,000	20,000	...	...	10	90	0	Full set of channels, 2 hours.
10–13	2 p. m.	600,000	50,000	...	...	10	300	0	Full set of channels, 2 hours.
10–13	5 p. m.	80,000	6,000	18,000	4,000	10	200	0	Full set of channels, 2 hours.
10–14	7 a. m.	10,000	5,000	...	...	10	200	0	Full set of channels, 2 hours.
10–14	10 a. m.	400,000	60,000	...	...	10	100	0	Full set of channels, 2 hours.
10–15	7 a. m.	46,000	21,000	...	...	10	40	0	Full set of channels, 2 hours.
10–15	10 a. m.	170,000	20,000	...	...	10	60	0	Full set of channels, 2 hours.
10–15	2 p. m.	80,000	15,000	120,000	9,000	10	50	0	Full set of channels, 2 hours.
10–15	5 p. m.	20,000	10,000	60,000	8,000	10	40	0	Full set of channels, 2 hours.
10–18	7 a. m.	600,000	40,000	160,000	50,000	7	15,000	600	Full set of channels, 2 hours.
10–18	10 a. m.	1,750,000	60,000	320,000	50,000	7	6,700	1,110	Full set of channels, 2 hours.*
10–18	2 p. m.	1,400,000	20,000	180,000	14,000	7	58,000	2,300	Full set of channels, 2 hours.*
10–18	5 p. m.	180,000	11,000	130,000	13,000	7	9,200	1,700	Full set of channels, 2 hours.
10–19	7 a. m.	40,000	4,000	70,000	5,000	7	3,000	150	Full set of channels, 2 hours.
10–19	10 a. m.	900,000	80,000	270,000	11,000	7	850	150	Full set of channels, 2 hours.
10–21	7 a. m.	250,000	30,000	...	...	5	9,100	1,600	Full set of channels, 2 hours.
10–21	10 a. m.	2,500,000	40,000	...	...	5	280	60	Full set of channels, 2 hours.
10–21	2 p. m.	...	...	...	...	5	12,900	1,200	Full set of channels, 2 hours.
10–21	5 p. m.	300,000	75,000	...	...	5	...	...	Full set of channels, 2 hours.
10–22	7 a. m.	60,000	10,000	120,000	40,000	5	18,400	3,000	Full set of channels, 2 hours.
10–22	2 p. m.	145,000	17,000	78,000	22,000	5	2,050	500	Full set of channels, 2 hours.
10–22	5 p. m.	320,000	80,000	124,000	64,000	5	129,000	5,000	Full set of channels, 2 hours.
10–23	7 a. m.	210,000	4,000	...	...	5	21,000	900	Full set of channels, 2 hours.
10–23	10 a. m.	970,000	39,000	...	...	5	90,000	4,000	Full set of channels, 2 hours.
10–23	2 p. m.	1,500,000	300,000	...	...	5	78,000	15,000	Full set of channels, 2 hours.
10–25	7 a. m.	...	...	...	...	12	80	0	Full set of channels, 2 hours.
10–25	10 a. m.	...	...	...	...	12	50	0	Full set of channels, 2 hours.
10–26	7 a. m.	...	...	238,000	36,000	10	80	10	Half set of channels used.
10–26	10 a. m.	...	...	76,000	35,000	10	15,000	1,500	Half set of channels used.
10–26	2 p. m.	...	...	150,000	34,000	10	...	...	Half set of channels used.
10–26	5 p. m.	...	...	100,000	32,000	10	26,000	5,000	Half set of channels used.
10–27	7 a. m.	...	...	110,000	26,000	7	20,000	1,700	Half set of channels used.
10–27	2 a. m.	...	...	360,000	28,000	7	9,000	1,500	Half set of channels used.
10–28	7 a. m.	...	...	60,000	20,000	5	22,300	600	Half set of channels used.
10–28	10 p. m.	...	...	53,000	19,000	15	30	0	Half set of channels used.
10–28	2 p. m.	...	...	110,000	29,000	10	400	10	Half set of channels used.

10-28	5 p. m.	....	....	73,000	18,000	7	200	10	Half set of channels used.
10-29	7 a. m.	....	....	46,000	10,000	7	60	10	Half set of channels used.
10-29	2 p. m.	....	....	92,000	27,000	5	9,000	1,700	Half set of channels used.
10-29	5 p. m.	....	....	310,000	115,000	....	5,000	30	Half set of channels used.
11- 2	7 a. m.	....	....	91,000	24,000	7	1,100	1,200	Full set of channels.
11- 2	10 a. m.	....	....	94,000	18,000	7	520	70	Full set of channels.
11- 2	12 m.	....	....	118,000	33,000	7	260	20	Full set of channels.
11- 2	2 p. m.	....	....	120,000	26,000	7	200	10	Full set of channels.
11- 2	5 p. m.	....	....	101,000	28,000	7	200	20	Full set of channels.
11- 3	7 a. m.	....	....	38,000	11,000	10	50	0	Full set of channels.
11- 3	10 a. m.	....	....	....	....	10	300	0	Full set of channels.
11- 3	2 p. m.	....	....	74,000	26,000	10	200	0	Full set of channels.
11- 3	5 p. m.	....	....	44,000	12,000	10	0	0	Full set of channels.
11- 4	7 a. m.	....	....	35,000	13,000	12	200	100	Full set of channels.
11- 4	10 a. m.	....	....	24,000	10,000	12	20	0	Full set of channels.
11- 4	2 p. m.	....	....	63,000	13,000	12	100	0	Full set of channels.
11- 4	5 p. m.	....	....	450,000	140,000	12	200	0	Full set of channels.
11- 5	7 a. m.	....	....	90,000	19,000	5	20	0	Full set of channels.
11- 5	10 a. m.	....	....	120,000	39,000	5	600	200	Full set of channels.
11- 5	2 p. m.	....	....	240,000	50,000	5	80	10	Full set of channels.
11- 5	5 p. m.	....	....	71,000	18,000	5	2,600	700	Full set of channels.
11- 6	7 a. m.	....	....	54,000	19,000	5	450	180	Full set of channels.
11- 6	10 a. m.	....	....	43,000	17,000	5	700	180	Full set of channels.
11- 6	2 p. m.	....	....	40,000	12,000	5	3,200	1,100	Full set of channels.
11- 6	5 p. m.	....	....	75,000	20,000	5	100	30	Full set of channels.
11- 7	7 a. m.	....	....	10,000	4,000	7	10	0	Full set of channels.
11- 7	10 a. m.	....	....	47,000	9,000	5	5	0	Full set of channels.
11- 7	2 p. m.	....	....	34,000	6,000	7	35	8	Full set of channels.
11- 7	5 p. m.	....	....	58,000	13,000	7	52	8	Full set of channels.
11- 8	7 a. m.	....	....	30,000	2,500	7	11	2	Full set of channels.
11- 8	10 a. m.	....	....	65,000	16,000	7	53	4	Full set of channels.
11- 8	2 p. m.	....	....	36,000	4,800	7	56	11	Full set of channels.
11-12	7 a. m.	230,000	60,000	16,000	5,000	....	....	....	Chlorine meter not working.
11-12	10 a. m.	120,000	30,000	60,000	16,000	....	....	....	Chlorine meter not working.
11-12	2 a. m.	42,000	8,000	73,000	24,000	....	....	....	Chlorine meter not working.
11-12	5 p. m.	56,000	25,000	71,000	15,000	....	....	....	Chlorine meter not working.
11-13	7 p. m.	36,000	8,000	20,000	10,000	....	....	....	Chlorine meter not working.
11-13	10 a. m.	49,000	26,000	120,000	43,000	....	....	....	Chlorine meter not working.
11-13	2 p. m.	84,000	30,000	110,000	22,000	....	....	....	Chlorine meter not working.
11-13	5 p. m.	96,000	40,000	100,000	24,000	....	....	....	Chlorine meter not working.
11-15	7 a. m.	120,000	54,000	53,900	9,000	....	....	....	Chlorine meter not working.
11-15	10 a. m.	560,000	12,000	70,000	12,000	....	....	....	Chlorine meter not working.
11-15	2 p. m.	124,000	25,000	40,000	20,000	....	....	....	Chlorine meter not working.
11-15	5 p. m.	270,000	90,000	122,000	49,000	....	....	....	Chlorine meter not working.
11-16	7 a. m.	135,000	40,000	118,000	42,000	....	....	....	Chlorine meter not working.
11-16	10 a. m.	590,000	50,000	120,000	40,000	....	....	....	Chlorine meter not working.
11-16	2 p. m.	110,000	50,000	85,000	20,000	....	....	....	Chlorine meter not working.
11-16	5 p. m.	120,000	50,000	78,000	15,000	....	....	....	Chlorine meter not working.
11-21	2 p. m.	....	....	22,000	10,000	....	....	....	Chlorine meter not working.
11-21	5 p. m.	....	....	16,000	5,000	10	650	60	Full set of channels.
11-22	7 a. m.	....	....	107,000	19,000	10	480	80	Full set of channels.
11-22	10 a. m.	70,000	34,000	143,000	25,000	7	30	0	Full set of channels.
11-23	7 a. m.	15,000	4,000	....	....	7	35	0	Full set of channels.
11-23	10 a. m.	24,000	20,000	....	....	5	20	0	Chlorine added before entering west tank.
						5	100	10	Chlorine added before entering west tank.

TABLE No. 25.—Tabulation of Bacterial Results at El Dorado, Kan.—*concluded.*

DATE.	Hour.	Raw sewage.		Septic tank effluent.		Chlorine. p. p. m.	Treated effluent.		Remarks.
		Total.	Red colonies.	Total.	Red colonies.		Total.	Red colonies.	
11-23	2 p. m.	60,000	30,000			5	50	0	Chlorine added before entering west tank.
11-23	5 p. m.	50,000	29,000			5	100	10	Chlorine added before entering west tank.
11-24	7 a. m.	18,000	9,000			7	60	0	Chlorine added before entering west tank.
11-24	10 a. m.	40,000	15,000			7	20	0	Chlorine added before entering west tank.
11-24	2 p. m.	28,000	14,000			7	40	0	Chlorine added before entering west tank.
11-24	5 p. m.	15,000	10,000			7	20	0	Chlorine added before entering west tank.
11-29	10 a. m.	...	...	...	...	4	35,000	10,000	Chlorine added before entering west tank.†
11-29	2 p. m.	...	...	...	...	4	13,000	3,800	Chlorine added before entering west tank.†
11-29	5 p. m.			...	...	4	20,000	500	Chlorine added before entering west tank.†
11-30	7 a. m.	214,000	85,000	...	...	4	60	0	Chlorine added before entering west tank.
11-30	10 a. m.	870,000	440,000	...	...	4	120	15	Chlorine added before entering west tank.
11-30	2 p. m.	400,000	290,000	...	...	4	130	30	Chlorine added before entering west tank.
11-30	5 p. m.	...	...	...	...	4	5,500	2,300	Chlorine added before entering west tank.
12- 1	7 a. m.	60,000	40,000	...	...	5	40	0	Chlorine added before entering west tank.
12- 1	10 a. m.	200,000	83,000	...	...	5	20	10	Chlorine added before entering west tank.
12- 1	2 p. m.	250,000	90,000	...	...	5	60	0	Chlorine added before entering west tank.
12- 1	5 p. m.	175,000	90,000	...	...	5	120	20	Chlorine added before entering west tank.
12- 2	7 a. m.	80,000	40,000	...	...	5	20,000	8,000	Chlorine meter stopped during night.
12- 2	10 a. m.	330,000	140,000	...	...	5	8,000	5,000	Chlorine meter stopped during night.
12- 2	2 p. m.	438,000	130,000	...	...	5	540	130	Chlorine meter stopped during night.
12- 2	5 p. m.	420,000	20,000	...	...	5	500	200	Chlorine meter stopped during night.
TESTS ON RAW SEWAGE—2-HOUR PERIOD OF CONTACT.									
11-23	7 a. m.	15,000	4,000	...	...	6.4	900	200	
11-23	7 p. m.	15,000	4,000	...	...	9.6	20	0	
11-23	10 a. m.	24,000	20,000	...	...	5.0	80	0	
11-23	2 p. m.	60,000	30,000	...	...	5.0	50	0	
11-24	10 a. m.	40,000	15,000	...	...	6.8	300	0	
11-24	2 p. m.	28,000	14,000	...	...	6.8	2,000	600	
11-24	5 p. m.	15,000	10,000	...	...	8.2	50	0	
11-30	7 a. m.	214,000	35,000	...	...	5.0	1,500	800	
11-30	10 a. m.	820,000	440,000	...	...	4.1	300	50	
11-30	2 p. m.	400,000	290,000	...	...	4.1	500	500	
11-30	5 p. m.	...	...	...	...	4.0	25,000	14,000	Stored at 20° C. 24 hours.
12- 1	7 a. m.	260,000	40,000	...	...	9.6	60	20	
12- 1	10 a. m.	200,000	83,000	...	...	5.0	360	90	
12- 1	2 p. m.	250,000	90,000	...	...	5.0	280	40	
12- 1	5 p. m.	175,000	90,000	...	...	6.0	300	50	
12- 2	7 a. m.	80,000	40,000	...	...	9.6	600	70	
12- 2	10 a. m.	330,000	140,000	...	...	5.0	600	90	
12- 2	2 p. m.	438,000	130,000	...	...	5.0	106	40	
12- 2	5 p. m.	420,000	20,000	...	...	6.0	630	200	

*Septic action in channels.
†Samples stored for 24 hours at 20° C.

GENERAL INDEX.

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ENGINEERING BULLETIN No. 10.

The Present Development of Transmission Lines in Kansas.

WITH APPENDIX:

THE CALCULATION OF IRON WIRE LINES.

BY

F. ELLIS JOHNSON.

UNIVERSITY ENGINEERING EXPERIMENT STATION,

LAWRENCE, KANSAS.

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in the industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of Engineering Departments.

The Station designs to issue bulletins, of which this is the tenth number, containing the results of investigation that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

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FOREWORD.

The development of the power transmission business in Kansas has been so recent and so modestly carried forward that there has been no source available from which one might learn of its extent or practice. It has seemed, therefore, that a survey was worth while, and might be of some value as well as a source of satisfaction to those most loyally interested in the welfare and advancement of the state.

Especial acknowledgment is due both Dean Walker and Professor Shaad, now acting dean, for their interest in providing the means and the opportunity for this survey. This occasion may also be taken to express appreciation of the courtesy of those managers and officials who have given time in interviews and filling blanks that this report might be as accurate as possible.

F. ELLIS JOHNSON.

LAWRENCE, KAN., June 1, 1918.

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ENGINEERING EXPERIMENT STATION.

BULLETIN No. 10. JUNE 1, 1918.

The Present Development of Transmission Lines in Kansas.

The Calculation of Iron Wire Lines.

By F. ELLIS JOHNSON, *Assistant Professor of Electrical Engineering.*

Contents.

The Present Development of Transmission Lines in Kansas.

THE GROWTH OF TRANSMISSION LINES.

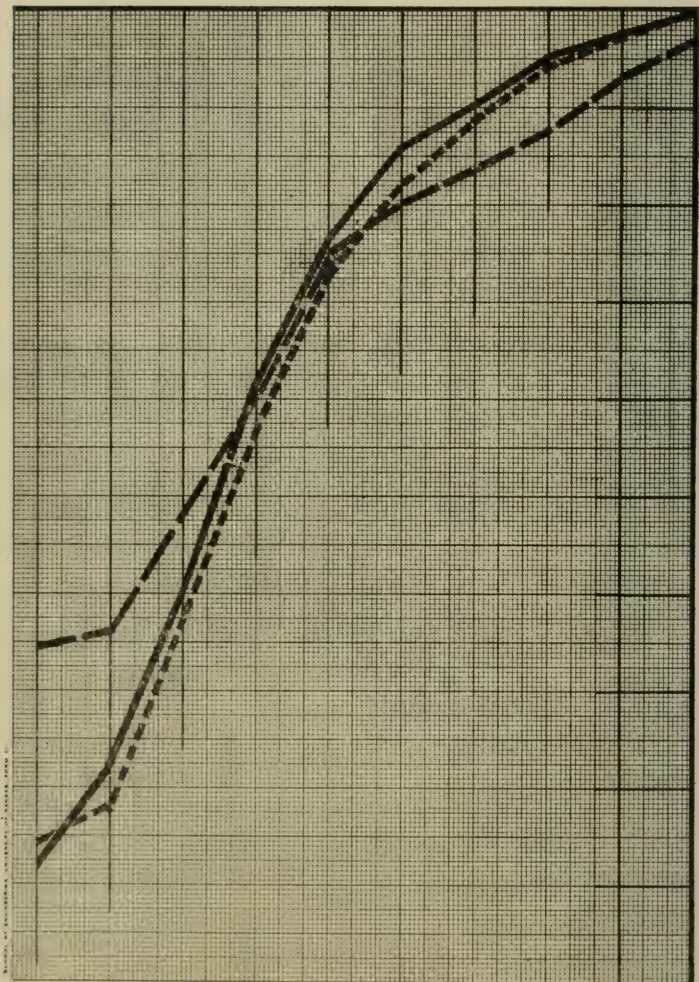
In April of 1918 there were 1763.50 miles of transmission lines in Kansas. This statement is even more significant than it may be surprising, because there are no especially notable hydroelectric developments in the state, and these miles of line out across the prairie represent the force and growing appreciation of the "central station" idea. It is the purpose of this brief report to show the rapid growth and present development of these lines as indicative of their future growth and importance.

It was in 1906 that the first line was built in the state, but the real development did not begin until 1910, in which year there were 43.5 miles of line built to serve four towns. This first transmission line, of which seven miles was in Kansas, was built by the Empire District Electric Company to supply Galena, Kan., and Joplin, Mo., from their hydroelectric plant at Lowell, Kan. It was a 3-phase, delta connected, 25-cycle line, operating at 33,000 volts. The conductors, No. 4 copper, were supported by 35-foot poles spaced 132 feet apart. This line of historical interest is now a part of the Empire District's network, which will be referred to later in this report.

Following 1910 the mileage quickly doubled and trebled, while the most marked growth has occurred since the world war began. The present 1763.50 miles of line supply 169 towns and municipalities, serving a population of over 130,000, beside many mines, mills and industries. The accompanying tabulation and curves show graphically the rapidity of this growth.

Year.	Miles added.	Towns added.	Population.
1906	7.0	1	6,096
1910	43.5	4	7,600
1911	44.0	6	11,011
1912	102.0	11	7,701
1913	86.0	13	7,475
1914	193.5	18	10,170
1915	293.5	34	29,411
1916	439.25	36	24,623
1917	378.75	36	24,210
1918	176.0	11	*3,327
Totals	1,763.5	169	131,624

* Incomplete.



GROWTH OF TRANSMISSION LINES IN KANSAS,
1909 TO MAY 1, 1918.

	Vertical scale unit.
Solid line = total mileage....................	200 miles
Dotted line = number of towns....................	20 towns
Dash line = population (excluding rural)..........	20,000 pop.

CHART PRINTED UP-SIDE-DOWN.
TURN BOOK TO READ CURVES.

The most striking statistics with respect to the lines are these. Of the 166 towns on which we have data, only 22 had previously enjoyed electric service; even more significantly, 108 towns, 64 percent of the total 169 served, are of less than 500 population. The importance of the transmission lines in bringing to small communities the luxury of city life, as represented in the cheer of electric light and the convenience of electric power for domestic purposes, is thus emphasized. In the larger towns served, as well as in the smaller in which the transmission line has replaced the local plant, there is an occasional reduction of rates; but more often, at the same rate, there is a decided improvement in the service and a lengthening of the hours of service from mere "dark till bedtime" to twenty-four-hour service. This is due, of course, to the greater reliability and economy of the large central station as against the small unit with its inexpert attendants.

ORIGIN OF LINES.

First, in a study of the transmission lines in Kansas, their origin may be considered, and it was hoped to discover for each line whether the initiator was some ambitious power-company manager or a public-spirited local citizen. The purpose of this inquiry was to determine how wideawake and anxious to serve the power companies have been, and also to what extent the intelligence and pride of the local Kansas community would lead to such a public undertaking. Unfortunately, the answers are probably the most unreliable data that was secured, for so evidently in many cases the official questioned was anxious to claim for himself the honor, or, on the contrary, wished to show that the other party to the bargain sought him. It is clear, however, that the leaders of the community have often shown initiative, and that equally so the companies have been very glad to entertain the proposition, oftentimes working patiently to secure the line for the new business it represented to them.

It is worthy of note that the building of a transmission line may represent the breaking down of local rivalry and prejudice between neighboring towns. There are a few cases in the state where this spirit of rivalry has prevented transmis-

sion-line service, to the disadvantage of the communities concerned, but, on the other hand, many of the lines now in operation are the accomplishment of a new spirit of coöperation which will doubtless extend to other affairs of the business and social life of the neighboring communities.

AGREEMENTS FOR SERVICE.

The agreements between the communities served and the power companies represent a varied lot of conditions, of which the following may be noted:

(1) The power company secures a franchise in the town, builds its own distribution lines and the transmission line to supply it.

(2) The city owns its own light plant and distribution system, decides to shut down the plant and buy power from the transmission line at the city limits.

(3) The city builds its own distribution system and its own transmission line, and buys power at the company's switchboard.

(4) The town is unincorporated, and the transmission line passing through or near by agrees to supply individual consumers by individual contract with special agreement or guarantee from merchants for the street lights, if any.

From these type conditions the principal points may be chosen for brief discussion.

The franchise of an electric-light company is so often a thing to conjure with that its essentially simple and just relations are often forgotten. The varied stipulations of existing franchises are too numerous for analysis in this report, but attention may well be called to the fact that a franchise is properly, in substance, but an agreement between a community and a power company for service. In return for exclusive privileges for a term of years and construction rights, the company agrees to furnish adequate and satisfactory service at certain rates. Perhaps the greatest objection to the franchises now holding is that they are too iron-bound. A franchise, like a business agreement between individuals, should be subject to change or cancellation whenever it becomes unprofitable and unsatisfactory to either party, while the provision for change or cancellation should adequately protect both parties from loss. A town gives a franchise for twenty years, binding it-

self to the service of a certain company, irrespective of the service given or of the probable changes of those years, when properly, provision should be made for canceling the agreement, while protecting the company stockholders from loss. On the other hand the company binds itself to give valuable service, of which the cost may rise from many causes—as, for example, during these war times—to the point where the business becomes unprofitable unless the standards of service are lowered. The usual difficulty of raising the rates works to the injury of the company, and back upon the public in the service rendered. All of which suggests that if the rates were at all times subject to prompt and fair changes, ordinarily they might be a little lower, since there would be no hedging necessary to protect against the "lean years." Further, if there were no time limit to the franchise, the company would know that as long as their service was satisfactory the privilege of doing business would be theirs, and that in any event protection was provided for the investment, and hence the common necessity of facing the later years of the franchise term with the question of the renewability of the franchise agreement and the possibility of forced sale or "digging up stakes" would be obviated. Along with the necessity of anticipating loss would go the high rates figured to provide against it, thus again the town should benefit. To restate: A franchise should be revocable upon the pleasure of the municipality, and the company's property investment should not be jeopardized by the expiration of a certain term of years. Rather, the company should be encouraged to good and adequate service by the prospect that fair dealing would perpetuate without limit its place as a factor in the community life.

When a city owns its own system and determines to shut down its plant and become a purchaser of power, a common form of agreement guarantees that the bill for power will not be less than a certain amount per year for a term of years. It is noteworthy, however, that towns lying along the route of heavy industrial transmission lines and owning their own distribution systems enjoy the same rates and conditions of sliding scale as the industries supplied by the power company. The Kansas Gas & Electric Company supplies several towns upon this basis.

Arrangement is sometimes made where the city owns its

own system and buys power, that the power company shall maintain the city's system. This is especially advisable when a municipality is small; since then the system is seldom properly maintained, and unless this provision is made, the company, through no fault of its own, becomes responsible in the eyes of the public for the poor service resulting; and further, the breakdowns on the city's distribution lines become a menace to the stability of the service on the company's system as a whole. For this reason some companies insist that their own men maintain all the lines served, and charge extra for such maintenance.

There are a number of towns in the state that have built their own transmission lines, and some of these towns buy power at the station switchboard. While because of the switchboard rate and the pride satisfied in owning their own lines, these places may seem especially fortunate, it is doubtful whether the proposition is generally a wise one. In the first place, it may prove from the business standpoint a tactical error, in so far as by planting their pole-line investment substantially in the ground they bind themselves in a permanent way to the service of the one company, and are not prepared to bargain for new contracts as would be the case if the company had made the investment to come and serve them. In the second place, they undertake all the losses incident to transmission, the losses of the line and in the transformers and the accidental losses. These losses very often amount to so much more than anticipated by the lay public, who have perhaps heard of the high efficiency of transformers and are unaccustomed to thinking in terms of load factor and all-day efficiency, that the net returns from the rates fixed to the consumers fail to meet the necessary charges of maintenance and interest and depreciation, let alone show a profit for a sinking fund to retire the bonds. It is very true that under any arrangement all these expenses must be paid, and that the consumer eventually pays them; but the fact is that the power company by its experience and expert employees is in better position to anticipate and meet the question of losses than the city, and so is better prepared to figure the cost of delivered power and keep this cost down. Also, as is commonly known, the municipal administration of our towns at its best is often unbusinesslike, and being political, is always anxious for an

immediately fine showing, usually at the expense of the future; and these low switchboard rates offer a temptation to fix the consumer's rates too low for sound business, with a fine present showing and a sure future settlement. Hence, it is recommended that, in general, the power company be encouraged to build the line, and the necessarily higher rates be paid for delivered power—leaving the problems in engineering and financing to the company—so that a very definite margin will be secured between the delivered cost to the city and the consumer's rate to pay for the administration of the business, the maintenance and extension of the distribution system.

Under those circumstances, where the power is to be secured from a municipally owned plant in a neighboring city, and the town must build its own line (since state laws permit a town to build a line to supply itself, but not to supply another), a reliable consulting engineer should be called upon to investigate the requirements and design the line, and the rates to consumers should be based upon his recommendation. Where these conditions are carefully and expertly met, the proposition is usually a very satisfactory one. It is noteworthy that a very few towns that own their own line have rented the use of all or a portion of it to some neighboring town, and in this way secure a revenue that, at least in one case, bids fair to soon pay not only the charges on the line but to return the original investment. Sharing the use of the line with another town, however, brings in additional losses on each kilowatt delivered, and the owner of the line should properly take this into account in figuring such a deal.

There is a very notable instance in the state where a group of towns realized more clearly than most others the value of coöperation, for we have the example of three towns; probably only one of which could have properly built to the fourth town for power, entering into partnership and building a line to the fourth city for their supply. It is noteworthy that the fourth city was keenly awake to the advantage of increasing its load by supplying its neighbors, and sent its representatives to help push the matter through. This is very interesting, representing the conscious accomplishment by municipalities of that coöperation which is automatically secured where the power companies build their lines out and form networks between cities.

RATES.

One of the pertinent questions in regard to service by transmission lines is that of rates, especially relative to the rates in similar communities served by a local plant. In general, the statement can be made that the rates of transmission-line service are no higher than those of the local plant, and, on the contrary, are often much lower. Furthermore, it is important to notice that just as in everyday affairs the quality and measure of the commodity purchased must be taken account of in considering the purchase price, so in this matter of electric service, the reliability and usual twenty-four-hour service furnished by the transmission line, backed by the large central station, must be considered in comparison with the intermittent and "dark-till-midnight" service of the ordinary oil-engine plant of the smaller or medium-size town. In the transmission-line towns under 250 population the average rate to the consumer is 12.7 cents; 250 to 500 population, 12.9; 500 to 750 population, 13.0; 750 to 1,000 population, 12.1; while in the larger towns the rate declines. This shows how uniform the rate is, on the average, in the smaller towns, as well as indicates the degree to which these places share the lower rates of the larger cities with their larger power plants.

An important point, though obvious, should at all times be remembered in comparing the rates of different transmission lines. The rates that are perfectly fair in one case, because of the length of line, investment, size of load and load factor, together with the cost of generation, may seem abnormally high in comparison with those of another line working under more favorable circumstances in some of these things. Hence, comparisons are indeed "odious" unless made after careful investigation.

SERVICE TO FARMERS.

In an agricultural state such as Kansas it is fair to ask to what degree these lines traversing the country serve the farms they pass. Of forty-three companies and cities operating lines, twenty-four report that they have farm customers. When asked whether they consider the farm load a desirable one and whether they wish to encourage the use of electricity by farmers, the opinion often expressed is that the average farm load is not sufficient to justify the expense of the trans-

former and the service lines at the same rate as the town customer. However, a number of managers foresee the possibilities of developing this business to the place where they can make terms that will be profitable to them, and still have the rural customer feel that he is not discriminated against. Some of these men now consider the special contract they offer the farmer along their lines an investment that will bring them future returns as he becomes accustomed to using electricity for more and more purposes. The present solution of the problem of serving the farmer is in some cases to require a bonus from him before service is given, and commonly to required a higher minimum than that usual in the city, so that the higher interest charges due to the larger investment and the heavier all-day losses may be met. A quotation from the report of one company expresses the situation very well as follows:

"We have between fifty and sixty farm customers, and did charge them $150 as a connection fee, which was about $100 above the cost of their transformer apparatus, etc. This has been raised, however, to about $175 above the cost of their transformer equipment. We think the farm business profitable when taken on the latter basis. The farm business would not be profitable without some such bonus, and in view of the fact that a private electric farm plant would cost considerably more than our charges and give a very limited service, we consider it good business both for ourselves and the farmers.

"At the end of the twenty-year contract we believe that the farm business will be profitable enough to take without further payment on the part of the farm customers, but of course limit our contract to twenty years in case it should not prove so."

In some places the use of electricity for farm purposes has been made especially successful by the coöperative power by several farmers. The cuts show activities of this sort, where the work of several farms bulks large enough to warrant a transformer wagon and motor for thrashing, baling hay and cutting ensilage. The particular instances shown are tapped on a 12,000 volt line out of Abilene.

POPULAR FEELING.

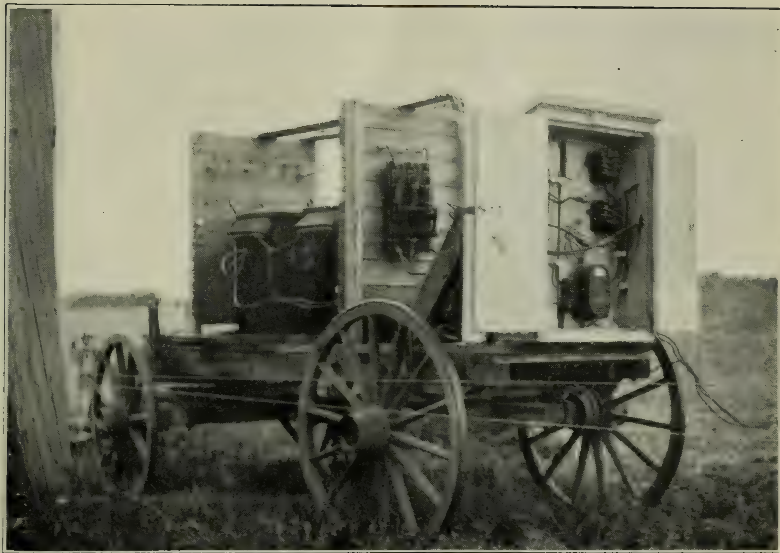
There is very little dissatisfaction with transmission-line service. Usually it is so much better than the average small town enjoys, or else is the first and only possible service for the community, that it becomes a matter of pride that "we have just as good service as the city." In the larger towns and the cities

served, the transmission line exists because it was able to outbid the local plant, and so is satisfactory for that reason.

The very contentment and peace that exist lead to stagnation, for very little effort was found anywhere throughout the state to popularize the service of the lines. Municipalities owning their own system seem content to have folks in general contented. Power companies, while running the usual ads in the papers and keeping busy with the natural growth in the business, do not attempt to take the consumer into their confidence, show him all about their business and awaken his pride in all the factors that are serving in his home and business and making his town attractive. Naturally the transmission lines seek to secure the power load of the local elevators and mills and garages, but little evidence is available to show that in any case they have stimulated the founding of any new local industry or small manufactory by advertising the availability of their power. The average of the answers to the question as to what percent of available business is yet uncaptured is 33 percent. The general impression given is that there is not much anxiety to capture this remaining 33 percent unless, having looked at a window display or stereotyped newspaper advertisement, it will come into the office to be lassoed.

INDUSTRIAL POWER LINES.

An intimate and detailed discussion of the transmission lines of the state can best be made with reference to the map showing them. Considering the natural resources of the state and the resultant industrial development, it may be readily conceived that the lines netting the southeastern portion are heavy-power industrial lines. It is interesting to note that here the first line built in the state has now grown to a network. The part of this network operated by the Empire District Electric Company constitutes the only 25-cycle system in the state. This system, together with that of the Kansas Gas and Electric Company, operating out of Pittsburg, Independence and Wichita, formed a group carrying the heaviest industrial loads and operating trunk lines at the highest voltage. Their load is growing so rapidly that there is difficulty, under war conditions, of securing material to keep pace with it. Most notable, perhaps, of the work under way is the 25-cycle, 60,000-volt line from Pittsburg



A Portable Transformer Station for Farm Power

Electric Power for Threshing

to Cherryvale, making available to the Kansas Gas and Electric Company System the power generated in the Empire District Company's big plant at Riverton. This makes possible a dump-power proposition for some industries, and represents a new condition for Kansas. When, as under present normal conditions, the Empire District Riverton plant has power to spare, this surplus may be sent west on this line and retailed to industries, such as a cement plant, at a price so low that they cannot afford to operate their own large and efficient stations. The power companies protect themselves by the provision that at any time, if for any reason they are unable to deliver this power from their surplus, at certain hours' notice the cement plant, for instance, must be prepared to supply itself and be cut off from the transmission line.

Indicative of the strides recently taken by these companies of this "industrial group," one company reports an increase from June, 1916, to June, 1917, of 18.4 percent in number of customers, with an accompanying increase of 51.5 percent in sales of current. These relative percentages indeed prove the increased business to be of industrial power. With this industrial load available, it is not surprising that the power companies of this group serve towns for lighting more as incidental to the power business, and that the extension of a line is often conditional upon some mill or industry adopting motor drive. One company figures that from 30 to 35 percent of the cost of a line must be in sight in yearly gross revenue to justify the building of an extension.

Out of Wichita, as the western center of the industrial power group, development at this time is especially rapid due to the oil fields. The line to Valley Center, Sedgwick, Newton and Halstead, first operated in 1911, now supplies 150 percent of its initial load; the Benton-Towanda-El Dorado line, operating first in 1915 (the oil-field line), now supplies 550 percent of its initial load; the Burrton-Buhler extension, opened in 1916, has risen to 117 percent.

AGRICULTURAL LINES.

From Garden City, in western Kansas, extends a unique development of transmission lines, totaling 117 miles; four miles operated at 4,400 volts; 29 miles at 6,600 volts, and 84 miles at 33,000 volts. The essential business of these lines

is to furnish power for 114 well pumps that supply water to irrigate approximately 50,000 acres of land. Three towns are lighted as an incidental matter. The plant furnishing the power is that of the refinery of the Garden City Sugar and Land Company, and a large portion of the land irrigated is under development by this company. The extensive use of electric power for such purposes is usually associated in our minds with hydroelectric power, hence it adds special interest that this plant is a steam-turbine plant.

Electricity is used more freely about the farm properties covered by this development than even by those progressive farmers on other lines who are encouraged by attractive rates. For instance, motors are not only used for grinding feed, cutting ensilage, and small power purposes, but electricity is used to light the barnyard, and even to heat the drinking water for the dairy herd in winter. This is possible, of course, only as surplus power for the company's own expenditure, and could not pay if purchased at any customary rate, although the increased milk production renders a real return. Where this company sells power the rate is 3 cents per kilowatt hour to all consumers.

While the Garden City development is now possible only as the centralized undertaking of a company with ample capital, it is a forerunner of the possible development of this part of the state.

NORTH CENTRAL GROUP.

Reference to the map showing the transmission lines of Kansas cannot fail to call attention to the heavy mileage radiating from Phillipsburg, Downs, Concordia, Blue Rapids, Abilene, and the Rocky Ford lines. The load on these lines may not be termed industrial, but consists principally of the lighting and small power uses of the ordinary Kansas towns. It is surprising how far they have extended to serve a small community; it may be presumed such extensions have proved profitable or they would not continue to make them. Naturally, throughout a district so heavily electrified, the public has become well educated to the idea of transmission lines, and it will be remembered that the instance of the coöperative use of electric power by farmers previously cited was found in this region. The public appreciation of the service rendered by

transmission lines in this part of the state is such that with the momentum acquired they will doubtless continue to extend and interlace the north central portion of the state completely. Already the coalescing of these original networks has begun, as shown by the purchase of the Downs system by the same interests assuming control at Concordia.

Even while the data for this survey was being collected, the demands of the service required by Camp Funston brought about a junction between the Rocky Ford system and that of the Riverside Light, Power and Gas Company, operating out of Abilene. Thus from Abilene as a center, we now have three power-transmission companies joining their lines in coöperation to serve an extensive territory. This process will continue, and will mean the guarantee of greater continuity of service and economy of operation.

Elsewhere about the state are the single and branched lines, each of which, according to the degree in which it has been well planned and consequently gives satisfactory service and returns, will become the trunk from which new lines may be expected to grow.

CONSTRUCTION FEATURES.

The most striking feature of the actual lines themselves is the fact that 497 miles, over 29 percent of the total 1716. miles upon which data is available, are iron lines. This is so noteworthy that it has been deemed worth while to add an appendix to this report, especially discussing the use of iron conductors. There are but three aluminum lines in the state. The first was the steel-cored aluminum, single-phase line built by the town of Pomona to secure electric service from the municipal plant at Ottawa; another constitutes one section of the Kansas Gas and Electric Company's network centering at Wichita, while the third is a recent extension of the Rocky Ford system. Copper-clad wire has been used in several cases, probably most by the Concordia, system, and as far as could be learned, with satisfaction.

Of the pole lines, 153.75 miles are of steel poles. There is one concrete pole line in the state. These concrete poles are 35 feet long and are spaced 235 feet apart. They were erected in 1910, and have given excellent satisfaction. Of the remaining 1557.0 miles of wooden poles, all are butt-treated but 150

miles. The only companies reporting the use of poles entirely treated are the Central Kansas Power Company, of Gypsum, and the Riverside Company, of Abilene, which have several miles of creosoted yellow pine. One or two companies have recently expended quite large sums in reinforcing their wooden poles by excavating about each pole, shaving and treating the butt, and then placing a reinforced concrete shell about it.

With few exceptions, ordinary wooden cross-arms are used; steel "wishbones" appear on but few lines.

Steel bayonets and guard wires are common on many of the higher-voltage or more important lines. One company mounts the guard wire on glass insulators on the bayonets.

Contrary to common belief, single-phase lines constitute but 21.4 percent of the total mileage; the remainder is all three-phase, and is all delta connected except for 237.75 miles.

In general, with respect to the construction of the lines, it may be said that they are usually satisfactorily built, mechanically. The criticism to be made is that too many are well built, but not well engineered. A line may stand the stress of weather and look like a pretty decent job; it may even deliver the required power at the load end; but still true economy may be lost in construction, so that the resultant line losses or interest charges, if properly taken account of, may show the job to be a poor one, indeed, for the conditions under which it must serve.

Transformer sizes used, also, often appear to be the result of expediency, with too little care given to relative cost of power wasted and interest charges on investment in transformers of proper rating.

THE ECONOMY OF TRANSMISSION LINES AND THEIR FUTURE DEVELOPMENT.

It is but a step from the economical engineering of the line itself to the broader question of the economy of the line as a business proposition. Careful consideration of the evident facts of any one of several lines in the state suggests that the building of a transmission line, in spite of all the desirability of its service, is not a matter in which local pride or enthusiasm should lead anyone without due consideration of whether it will really be a paying proposition. Measured by the added attractiveness that is lent to the social life and the conveniences

afforded by electric service when introduced into the average small town, it is true that the community could usually well afford to pay heavily for the transmission line itself, and even stand an annual deficit in meeting the charges; however, when a private company is organized to build a line to serve a small place, especial care should be taken to figure the economic possibilities of the line. It is a serious matter for the building of other lines in the future to have any one of the lines in service fail to show a proper return on the investment.

The future development of the transmission-line business in Kansas is definitely assured by the general success of the lines now in operation. Not only is the public becoming well educated to the advantages of transmission-line service, but the responsible public officials, as well as many of the power companies themselves, are beginning to have a clearer understanding of the advantages of the large central station with its distributing system in competition with the small local plant. It is especially worthy of consideration that the difficulties of transportation and of fuel supply, the congestion of the electrical and power machinery industries, and the deflection of money to war purposes, are all factors that, carefully considered, should tend steadily to the further extension of transmission lines as a wise policy of conservation and sound economics.

APPENDIX.

The Calculation of Iron Transmission Lines.

The use of iron wire on 497 miles of transmission lines in the state of Kansas, over 29 percent of the total mileage, indicates forcibly the importance of reducing the problem of figuring iron wire for transmission purposes to a basis as well and commonly understood as copper is now. The truth probably is that, while the initial soaring of the price of copper early in the war forced the adoption of iron in many cases as an economical expedient, familiarity with the problems arising in its use and its permanently cheaper price relative to copper, even in peace times, will insure iron wire a field of usefulness in appropriate places commonly in the future.

At present, even among those building iron transmission lines, there is a good deal of uncertainty in its use that is unnecessary. Among others who have become familiar with some of the phenomena attending the operation of iron lines there is a lack of understanding of the reasons for its behavior. With the idea of attempting in a modest way to help clear up this situation, this appendix is added to the foregoing report.

Since the calculations for three-phase lines can be so readily made upon a single-phase basis, it seems worth while to review very briefly and simply the essential features of a single-phase transmission line and explain the effect of using a magnetic conductor, such as iron, in place of the customary nonmagnetic copper. The electric pressure applied at the terminals of the line forces a current to flow out and back, overcoming the impedance of the line. We are accustomed to analyze this impedance into its three components—the resistance, the inductive reactance, and the capacity reactance of the line. It is obvious that, if we arrive at an understanding of the changes in these three factors when iron is used in place of the familiar copper, we may hope not only to understand the phenomena that occur in the operation of an iron line, but also to be able to predetermine or make the calculations for the line.

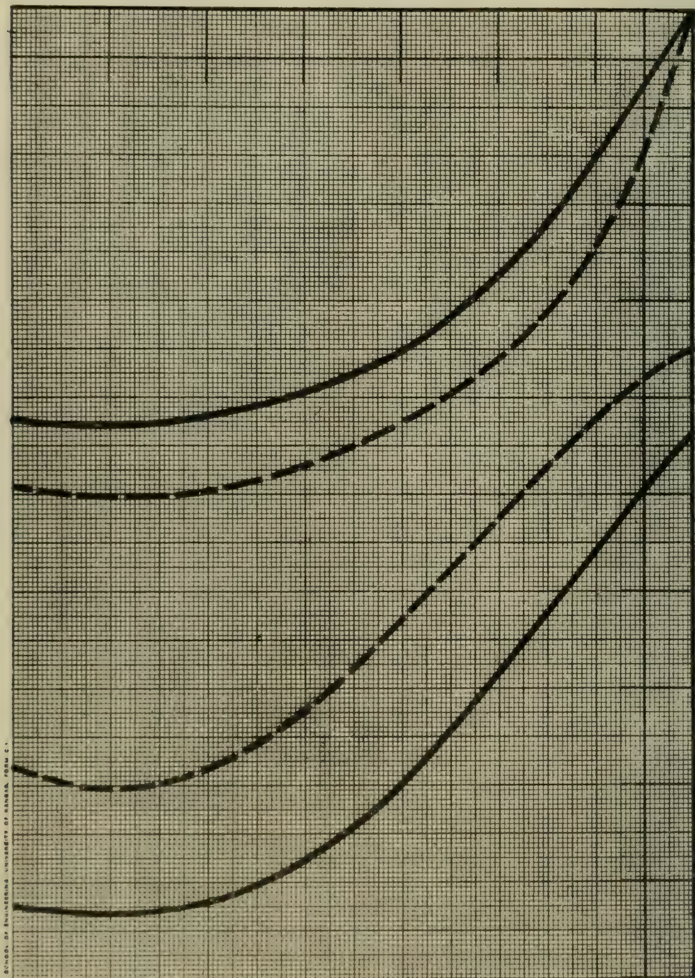
RESISTANCE.

In considering first the factor of resistance, attention must be called to the commonly neglected fact that the resistance of a copper wire to alternating current is really greater than that of the same wire to direct current. While it is true that this difference in the ordinary practical problem is so slight that it may be safely ignored, it is nevertheless real and more especially evident in the use of large solid copper conductors. This is due to that which is called "skin effect." It may be briefly explained by pointing out that, if we consider the conductor in question to be made up of a bundle of small filaments and then single out one of these, the magnetic field springing out about this filament when a current starts along it must cut all the other surrounding filaments. Hence, according to the well-known law of electromagnetic induction, there is a back electromotive force generated in these other filaments, whose magnitude in any one depends upon its distance from the original filament considered. Whether the current is increasing or decreasing, this effect always opposes its flow, and the net result is that, since this back electromotive force is less in those filaments bordering the exterior of the conductor, the current tends to flow in greater density near the surface of the wire. With continuous current, as there is no change in the magnetic field, there is no back electromotive force generated, hence no "skin effect," and the density of the flow is uniform throughout the conductor. In comparison then, when alternating current flows there is a virtual decrease in the effective cross-sectional area, and therefore a higher resistance.

As the "skin effect" just explained is really an electromagnetic effect, it is obvious that with the use of a magnetic conductor such as iron, whose permeability is many times that of copper, this increase of resistance offered to alternating current will be greatly magnified and must be considered. The accompanying curves show the variation in resistance for two sizes of iron wire for 60-cycle current. They not only show a remarkable increase in resistance as the current flow becomes greater, but indicate by their form their relationship to the magnetization curve of the iron.

CHARACTERISTIC CURVES FOR IRON WIRE.

Resistance to alternating current .... upper curves.
Internal inductive reactance .... lower curves.



	Horizontal scale unit.	*Vertical scale unit.*
Solid line for No. 6BB..................	2 amperes.	2 ohms.
Dash line for No. 4BB..................	2 amperes.	2 ohms.

CHART PRINTED UP-SIDE-DOWN.
TURN BOOK TO READ CURVES.

INDUCTIVE REACTANCE.

It is clear that "skin effect" accounts also for a decided increase in the inductive reactance of the circuit, since "skin effect" itself is a result of electromagnetic induction. Just as the increase of the resistance of copper to alternating current is negligible since the permeability of copper is so low, this "internal" reactance of a copper conductor is practically ignored, and the only inductive reactance considered is that due to the return conductor of the transmission line. This latter, the "external" reactance, governed by the size and spacing of the conductors and the frequency, is that which may be found figured out and presented in tables in the electrical handbooks. It may be demonstrated, therefore, that to this value found in the handbook for any particular case must be added another representing the internal reactance of the wire itself, when iron is to be considered. On the curve sheet previously referred to are shown the values of this internal reactance for the two samples mentioned, which, for the reasons given in explaining a rise of alternating current resistance, must also vary with the current. It is especially noticeable, as indicating the governing importance of this quantity, that in practical cases it may be equal to as much as 3 to 10 times the external reactance that would alone be considered for a similar copper wire.

CAPACITY REACTANCE.

The capacity of an iron transmission line will be just the same as that of an exactly similar copper line, since the condenser effect of a transmission line is governed only by the size and shape of the conductors, their length and distance apart, and the nature of the dialectric—air.

CALCULATION OF IRON LINES.

If, then, from test data, information is available with respect to the resistance and internal inductive reactance of the iron wire that it is proposed to use on a certain transmission line, the calculations for the line may be made according to any one of the methods commonly used in figuring a copper transmission line. Points to be emphasized are these: First, that since the above-described changes depend upon the per-

meability of the iron, test data upon samples of the specified iron must be used; second, that the value of the internal reactance is to be added to that given in the tables available in the handbook for copper wire of the same diameter and spacing; and third, that the capacity current is to be determined from the handbook tables precisely as for a copper line. With this fundamental data to work from there is no reason why the calculations for an iron line should not be made with the same degree of accuracy and satisfaction that is usual for copper lines.

It may be said with respect to the usual methods of approximation employed when account is taken of the charging current—and account must always be taken of the charging current with an iron line—that it is probable they will give less satisfaction in figuring for iron lines, because usually the capacity current is a much heavier component than ordinary. For this reason, in careful work, recourse should be taken to some one of the exact methods, such as the expotential series recommended by Steinmetz, or the more common formulas employing hyperbolic functions, given in the electrical engineer's handbooks.

IRON-LINE PHENOMENA.

Some of the phenomena of iron-wire lines may be briefly reviewed. First is the low current density that may be satisfactorily used. The explanation of this has been foreshadowed in the discussion with respect to resistance, and but a glance at the curves previously shown will indicate how badly the line will regulate and how much in percent the line loss will increase when the current is crowded up to high values. Obviously, the current must be kept to very low values and forethought be taken to avoid overloading to any considerable degree an iron line. This low permissible current value means a limitation to the amount of power that may be transmitted and explains the common statement that only a relatively light load can be handled over an iron line.

It is interesting to consider that while the capacity of an iron line is precisely the same as a similar copper line, perhaps the effect most often remarked on iron lines is the excessive charging current. It will be remembered that the charging current and capacity effects on copper lines are only considerable when the line is long, the voltage high, and the load re-

latively small, and it should be recognized that very commonly the conditions on iron lines approximate these except for magnitude. To keep the current low, as specified in the preceding paragraph, means not only that the connected load will be small, but that there will ordinarily be a tendency to use a rather high voltage. On any given line the charging current will vary directly as the voltage, so that in seeking relief from the limitation of a low current by raising the voltage the factor of the charging current is made of that much greater importance. Indeed, the capacity current and its consequent undesirable effect on the power factor at the central station is usually a greater evil than the higher line loss and poorer regulation due to the greater line current resulting from operation at a lower voltage. It is largely a misunderstanding or lack of appreciation of the importance of this point that has given rise to such dissatisfaction and mishaps in operation as have occurred. Not only may the current-carrying capacity of the generator and step-up transformers be reached in accommodating this charging current, resulting in unnecessary heating, but there are several cases about the state where transformers have been burned out.

To give point to all this discussion it seems worth while to submit a concrete example. It is assumed in Case I that a load of 35 kw. at 90 percent power factor is supplied over a 3-phase line, 20 miles long, at a voltage of 22,000. In Case II the voltage is to be reduced to 11,000. The line is to be constructed of No. 6 B. B. iron wire with a 30-inch triangular spacing. The following tabulation shows the results as approximated by the split-condenser method, the characteristics of the line only being considered:

	Case I.	Case II.
Line voltage at load	22,000	11,000
Generator volts	22,000	11,780
Load current	1.02	2.04
Total charging current	1.516	0.758
Line current	0.972	1.908
Resistance per mile, R	10.2	11.2
Reactance per mile, X	2.72	3.72
Line loss	192.4	815.0
Generator current	1.402	1.84
Above in percent of load current,	137.5%	90.2%
Power factor at generator	65.8 leading	99.7 leading
Power factor at load	90.0 lagging	90.0 lagging
Regulation at load end	0.32%	7.18%

Attention may be called to the increased value of resistance and reactance per mile as the current is increased in the second case. With respect to the line loss, it should be noted that although it is increased more than four times yet it is still but 2.3 percent of the transmitted power. Although the load current at the receiver is doubled by the reduction in voltage, it is noteworthy that at the generator end the current is only 131.4 percent of that at the higher voltage; or explaining it even more significantly, at the high voltage the generator current is 137.5 percent of the load current, while at the lower voltage the current at generator is but 90.2 percent of the load current. Thus with the power factor in both cases 90 percent lagging at the load, at 22,000 volts the generator power factor is 65.8 percent leading, while at 11,000 volts the generator power factor is 99.7 percent leading. If the transformer be taken into account, it is apparent how much better the whole operation of the line will be when the voltage is reduced. While it is true that the regulation at the receiver or load end will be poorer, it is still but 7.18 percent.

To conclude the question of operating voltage, the statement may be made that for any iron line with a given average load condition there is a definite voltage at which its operation will be most satisfactory, and it is worth special pains to determine what that voltage is.

One of the points raised with respect to the use of iron is that the line must be relatively short. Little discussion upon this point is necessary, for the reason that it is well understood that the resistance drop and consequent line loss would increase in proportion, while the capacity effect which we have seen is so important would also increase directly. Thus it may be fairly admitted, the common statement is correct that iron is suitable only for short, lightly loaded lines, operated at a moderate voltage. While this conclusion may cover the ordinary applications, it is probably true that with careful and intelligent engineering satisfactory operation may be secured over greater distances than it is now acknowledged to be possible.

The pioneer days in the use of iron should be over when the man who proposes to build a line inquires relative prices, chooses iron because it is cheap, and builds a line according to copper calculations or similar to some other line that seems

to deliver the power at the receiver end. Experience with iron wire has now demonstrated not only that it may be used successfully, but that it is best either to understand its characteristics thoroughly and be able to calculate the line with intelligence, or to appropriate in advance a small part of the money that will be lost in its operation, if not properly designed, and spend it to secure the best-informed expert's advice in the matter.

SELECTED REFERENCES.

Iron and Steel Wire for Transmission Conductors. General Electric Review, June, 1916; page 488.

Characteristics of Iron and Steel Conductors. Electrical World, October 14, 1916; page 760.

Iron Wire for High-Voltage Lines. Electrical Review, September 22, 1917; page 496.

STATISTICS OF THE TRANSMISSION LINES OF KANSAS.

CHIEF CITY, COMPANY AND TOWNS SERVED.	Date first served.	Miles to serve town.	Owner of line.	Voltage.	Phase connection.	Conductor. Size.	Conductor. Material.	Conductor. Spacing (inches).
ABILENE.								
Riverside Light, Power & Gas Co. General office at Abilene.								
Sand Springs	1913	6	Company	12,000	Wye	Number 4	Copper	21
Enterprise	1914	5	Company	12,000	Wye	Number 4	Copper	28
Chapman	1915	12	Company	12,000	Wye	4½ mi. No. 6 7½ mi. No. 8	Copper Iron	28
Navarre	1915	14	Company	12,000	Wye	Number 8	Iron	28
Woodbine	1915							
Wakefield	1916	18	Company	12,000	Wye	Number 9	Iron	28
Detroit	1916	3	Company	2,300	Delta	Number 8	Iron	21
Talmage	1916	12	Company	12,000	Wye	8½ mi. No. 4 12½ mi. No. 9 8 mi. No. 6	Iron	28
Manchester	1916	5	Company					
Longford	1916	7	Company					
Oak Hill	1916	5	Company					
Solomon	1916	5	Company	12,000	Wye	Number 6	Copper	28
New Cambria	1917	8	Company	12,000	Wye	Number 8	Iron	28
Central Kansas Power Co	1917	7	Company	33,000	Delta	Number 8	Iron	32
Ramona	1917	14¾	Company	12,000	Wye	Number 8	Iron	21
Lost Springs	1917	6	Company					
Lincolnville	1917	5	Company					
Camp Funston	1917	14	Company	33,000	Delta	Number 6	Copper	30
Miltonvale	1918	14	Company	12,000	Wye	Number 6	Iron	28
Herington to Hope	1911	2	Company	2,300	Delta	Number 6	Copper	24
Central Kansas Power Co. of Gypsum.								
Gypsum to Assaria	1914	11½	Company	6,600 and 11,000	Wye	6 mi. No. 8 5½ mi. No. 8	Copper Iron	32
Riverside Light, Power & Gas Co.	1917	17	Company	33,000	Delta	Number 8	Iron	32
Bridgeport	1917	6½	Company	6,600 and 11,000	Wye	Number 8	Iron	.....
Mentor	1917	24½	Company	6,600	Single-phase	Number 8	Iron	.....
Smolan	1917							
Falun	1917							
Brookville	1918	13	Company	11,000	Single-phase	Number 6	Iron	21

Rocky Ford Milling & Power Co. Plant at Rocky Ford, general office at Abilene.								
Manhattan	1910	4½	Company	6,600	Delta	Number 0	Copper	36
Ogden	1913	16	Company	33,000	Delta	Number 6	Copper	36
Fort Riley	1913							
Alma	1917	39	Company	33,000	Delta	Number 6	Copper	30
McFarland	1917							
Kaw Valley Transm'n Co., St. George	1914	15	K. V. T. Co	6,600	Delta	Number 6	Copper	18
Randolph	1918	20	Company	6,600	Delta	10 mi. No. 6 10 mi. No. 6 Equiv. No. 6	Copper Iron Aluminum	30
Leonardville	1918	9						
ATCHISON.								
Atchison Railway, Light & Power Co.								
Troy	1910	18	Troy	6,600	Delta	Number 6	Copper	28
Lancaster	1914	17	Effingham	6,600	Single-phase	Number 6	Copper	28
Effingham	1914							
Everest	1915	24½	Extensions	....	....	....	....	....
Muscotah	1915							
Huron	1917	3						
BEATTIE.								
Beattie Electric Light Co.								
Home City	1912	7	Company	6,600	Delta	Number 8	Copper	12
BLUE RAPIDS.								
Marshall County Power & Light Co.								
Marysville	1915	15	Marysville Light & Power Co.	22,000	Delta	Number 6	Copper	24
Waterville	1915	5	Company	2,300	Delta	Number 6	Copper	....
Irving	1917	4	Irving	2,300	Single-phase	Number 6	Copper	....
BONNER SPRINGS.								
Bonner Electric & Manufacturing Co.								
Forest Lake	1913	3	Company	2,800	Delta	Number 10	Copper	20
Edwardsville	1913	2	Company		Single-phase	Number 12	Iron	
Holliday	1916	1½	Company	2,300	Single-phase	Number 10	Iron	....
Wilder	1916				Single-phase	Number 12	Iron	
Basehor	1916	8	Company	13,200	Single-phase	Number 10	Iron	28
Linwood	1916	12	Company	13,200	Delta	Number 8	Iron	30
Eudora	1916	6	Company		Single-phase	Number 10	Copper	
CENTRALIA.								
Corning	1915	10	....	13,200	Single-phase	Number 6	Copper	28
Goffs	1916	5	....	13,200	....	Number 6	Copper	28

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Towns Served.	Date first served.	Miles to serve town.	Owner of line.	Voltage.	Phase connection.	Conductor. Size.	Conductor. Material.	Conductor. Spacing (inches).
CONCORDIA.								
Gen. Eng. & Man. Co., New York City.								
Jamestown	1910	10	Company	13,200	Delta	Number 4	Copper	
Glasco	1912	15	Company					
Randall	1912	13	Company	13,200	Delta	Number 6	Copper	
Jewell City	1912	7	Company					
Mankato	1912	8	Company					
Scottsville	1913	6	Company		Single-phase	Number 8		
Kackley	1913	3	Company		Delta	Number 6		
Courtland	1913	6	Company	13,200	Delta	Number 6	Copper-clad steel.	
Formoso	1913	5	Company		Single-phase	Number 8		
Scandia	1913	6	Company		Single-phase	Number 8		
Burr Oak	1913	10	Company		Delta	Number 6		
Simpson	1914	5	Company	13,200	Delta	Number 8	Copper	
Aurora	1915	7	Company		Single-phase	Number 8	Iron	
Clyde	1915	16	Company		Delta	Number 4	Copper	
Clifton	1915	6	Company		Delta			
Vining	1915	2	Company	22,000	Delta			
Palmer	1915	9	Company		Delta	Number 6	Copper	
Linn	1915	5	Company		Delta			
Greenleaf	1915	8½	Company		Delta			
Washington	1915	5	Company		Delta			
Republic	1915	10	Company	13,200	Delta	Number 8	Iron	
Barnes	1918	7	Company			¼ inch	Strand Iron	
Agenda	1918	....	Company	22,000	Delta	....	....	
Cuba	1918	22	Company			Number 6	Iron	
DODGE CITY.								
Midland Water, Light & Ice Co.								
Ford	1916	31	Company	22,000	Delta	Number 6	Iron	
Bucklin	1916							
Minneola	1917	22	Minneola	22,000	Delta	Number 6	Iron	
Cimarron	1918	20	....	....	....	....	....	....
DOWNS.								
Gen. Eng. & Mfg. Co., New York City.								
Cawker City	1914	14	Company	13,200	Delta	Number 8	Copper	18
Glen Elder	1914							

Portis	1915	36	Company	13,200	Delta	Number 8	Copper	18
Harlan	1915							
Gaylord	1915							
Cedar	1915							
Claudell	1915							
Kirwin	1915							
EMPORIA.								
Hartford Light & Power Co.								
Hartford	1915	15	Company	6,600	Single-phase	Number 6	Copper	....
Neosho Rapids	1916	5	Company	6,600	Single-phase	....	Copper	....
FRANKFORT.								
Vermillion	1913	15	Vermillion	13,200	Single-phase	Number 6	Copper	....
GARDEN CITY.								
Garden City Sugar & Land Co.								
Holcomb	1915	117	Company	4 mi. 4,400	Delta	8 mi. No. 2	Copper	....
Deerfield	1915			29 mi. 6,600		14 mi. No. 4	Copper	....
Lakin	1915			84 mi. 33,000		95 mi. No. 6	Copper	....
GREAT BEND.								
Great Bend Water & Electric Co.								
Hoisington	1910	11	Company	16,500	Delta	Number 6	Copper	....
Dent's Spur	1910							
GREENSBURG.								
Johnson Electric Transmission Co.								
Haviland	1915	10	Company	6,600	Open delta	Number 6	Copper	....
HIAWATHA.								
Hiawatha Light & Power Co.								
Robinson	1916	10	Company	13,200	Single-phase	Number 6	Copper	....
Reserve	1916	9	Company	13,200	Single-phase	Number 8	Copper	....
HOLTON.								
Circleville	1916	23½	Cities cooperatively.	13,200	Single-phase	Number 8	Copper	28
Soldier	1916							
Havensville	1916							
HORTON.								
Whiting	1914	9	Cities	6,600	Single-phase	Number 8	Copper	....
Notawaka	1914	6				Number 8	Copper-clad	....

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Towns Served.	Date first served.	Miles to serve town.	Owner of line.	Voltage.	Phase connection.	Conductor. Size.	Conductor. Material.	Conductor. Spacing (inches).
HUTCHINSON.								
United Water, Gas & Electric Co.								
Nickerson	1912	11	Company	32,000	Delta	Number 4	Copper	36-48
Lyons	1916	18	Company					
Inman	1916	19	Company	35,000	Delta	Number 4	Copper	48
JUNCTION CITY.								
Union Light & Power Co.								
Fort Riley	1914	5	Company	53,000	Delta	Number 6	Copper	....
KINSLEY.								
Kinsley Electric Light & Power Co.								
Lewis	1916	10	Co. and City	7,200	Wye	Number 6	Iron	36
Belpre	1917	8	Co. and City	7,200	Wye	Number 8	Iron	24
Garfield	1918	10	Company	7,200	Wye	Number 6	Iron	....
KIOWA.								
O. K. Light & Power Co.								
Hardtner	1917	15 (Kan.)	Company	13,200	Open delta	Number 6	Iron	42
LYNDON.								
Osage County Light & Power Co.								
Quenemo	1914	10½	Company	6,600	Single-phase	Number 6	Copper	28
Melvern	1914	9	Company					
MARYSVILLE.								
Marysville Light, Power & Water Co.								
Herkimer	1917	6	....	6,600	Delta	Number 6	Iron	18
McPHERSON.								
Farmers; New Gottland church	1918	6	Cooperative	6,600	Single-phase	Number 6	Iron	28
OBERLIN.								
Norcatur	1916	22	Norcatur	13,200	Single-phase	Number 8	Copper-clad	36

OSKALOOSA.								
Moxley & Co.								
McLouth	1911	7	Company	6,600	Single-phase	Number 8	Copper	28
OTTAWA.								
Pomona	1914	11	Pomona	6,600	Single-phase	Number 4	Steel core, Aluminum.	36
PHILLIPSBURG.								
Phillipsburg Mill & Elevator Co.								
Glade	1915							
Speed	1915	21	Company	13,200	Delta	Number 6	Copper	
Logan	1915							
Agra	1917	12	Company	13,200	Delta	Number 8	Iron	
Stuttgart	1917							
Prairieview	1917	27	Company	13,200	Delta	Number 8	Iron	
Luctor	1917							
Long Island	1917							
PITTSBURG.								
Kansas Gas & Electric Co.								
Mine district	1912	11	Company	6,600	Delta	Number 2	Copper	21
Cherokee	1912							
Mines	1917							
Ringo	1917							
Arma	1917	20	Company	22,000	Delta	Number 2	Stranded copper	27
Franklin	1917							
Frontenac	1917							
Parsons	1918	55	Company	60,000	Wye	Number 0	Stranded copper	108
Cherryvale	1918							
Independence	1917	10	Company	22,000	Delta	Number 2	Copper	
Empire District Electric Co.								
(Plants at Lowell and Riverton).								
Galena	1906	7	Company	33,000	Delta	Number 4	Copper	
Baxter Springs								
Columbus								
Weir City	to	82	Company	33,000	Delta	Number 0 Number 2 Number 4	Copper	
Scammon								
West Mineral								
Mines and Railway	1918							
PLEASANTON.								
Pleasanton Electric & Power Co.								
Fulton	1917							
Prescott	1917	12 5 (Kan.)	Company	22,000	Single-phase	Number 8	Iron	36
Hume, Mo	1917							

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Towns Served.	Date first served.	Miles to serve town.	Owner of line.	Voltage.	Phase connection.	Conductor. Size.	Conductor. Material.	Conductor. Spacing (inches).
PRATT.								
Iuka	1916	18	Preston	6,600	Open delta	Number 8	Copper	30
Preston	1916							
SABETHA.								
Morrill	1912	9	Morrill	6,600	Single-phase	Number 6	Copper	26
Hamlin	1912							
Fairview	1914	19	Powhattan	13,000	Single-phase	Number 6	Copper	28
Powhattan	1914							
SENECA.								
Axtell	1912	12	Axtell	13,200	Single-phase	Number 6	Copper	28
Oneida	1912	9	Oneida	6,600	Single-phase	Number 6	Copper	28
STAFFORD.								
Zenith	1916	12	Sylvia	6,600	Single-phase	Number 8	Copper	28
Sylvia	1916							
WELLINGTON.								
City pumps	1915	16	City	13,200	Delta	Number 4	Copper	36
W. S. Light & Power Co	1915							
Western Sumner Light & Power Co.								
Mayfield	1916	21¾	Company	13,200	Open delta	Number 6	Iron	42
Milan	1916							
Argonia	1916							
Tri-County Light & Power Co.								
Viola	1917	19½	Company	13,200	Open delta	¼ inch	Stranded steel,	52
Milton	1917							
Norwich	1917							
Conway Springs	1917							

WICHITA.								
Kansas Gas & Electric Co.								
Valley Center	1911							
Sedgwick	1911	28	Company	60,000	Delta	Number 2	Stranded Copper.	
Newton	1911							
Halstead	1911							
Benton	1915							
Towanda	1915	33½	Company	22,000	Delta	Number 4	Copper	
El Dorado	1915							
Burrton	1916	25	Company	60,000	Delta	14 miles	Aluminum	
Buhler	1916					9 miles	Stranded iron	
Hesston	1917	18	Company	11,000	Delta	Number 4	Copper	
Moundridge	1917							
Whitewater	1917	10½	Company	22,000	Delta		Stranded iron,	
Augusta	1917	45	Company	22,000	Delta	37 mi. No. 1	Strd. copper,	
El Dorado oil fields	1917					8 mi. No. 4	Copper	
WILSON.								
Weber Electric Power Co.								
Dorrance	1913	8	Company	2,200	Delta	Number 6	Copper	24

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Town Served.	Poles.			Cost per mile.	Transformer, capacity or total load.	Percent motor-load.	Percent of available load captured.	Rates.	
	Length (feet).	Kind.	Spacing (feet).					Lighting.	Power.
ABILENE.									
Riverside Light, Power & Gas Co. General office at Abilene.									
Sand Springs	30	Cedar	200		90	100			
Enterprise	30	Cedar	150		90	50		(See footnote.*)	
Chapman	30	Cedar	240		45	50		"	
Navarre, Woodbine	30	Cedar	250			25	33	"	
						25	25	"	
Wakefield	30	Cedar	250		90	50		"	
Detroit	30	Cedar	200		17.5	25		"	
Talmage, Manchester, Longford, Oak Hill	30	Cedar	250		30	75		"	
					20	35		"	
					25	50		"	
					15	25		"	
Solomon	30	Cedar	250		75	50		"	
New Cambria	30	Cedar	250		15	50		"	
Central Kansas Power Co	30	Creosoted yellow pine	250		150	50		"	
Ramona, Lost Springs, Lincolnville	30	Cedar	250		22.5	25		"	
					30	50		"	
					22.5	25		"	
Camp Funston	30	Cedar	250		750	50		"	
Miltonvale	30	Cedar	250		75	50		"	
Herington to Hope	25	Cedar	150		45	15		"	
Central Power Co. of Gypsum.									
Gypsum to Assaria	30	Cedar	250		35			(See footnote.†)	
Riverside Light, Power & Gas Co	30	Creosoted yellow pine	250		150	50		"	
Bridgeport	30	Creosoted yellow pine	250		25	Mostly motor		"	
Mentor, Smolan, Falun	30	Cedar and yellow pine	300			50		"	
Brookville	30	Cedar	300		16			"	

Rocky Ford Milling & Power Co. Plant at Rocky Ford, general office at Abilene.									
Manhattan	35	Reinforced concrete	285	...	700	50	...	"	
Ogden, Fort Riley	40	Cedar	175	...	250	Power for railway	...	"	
Alma, McFarland	30	Cedar	250	...	...	...	...	"	
Kaw Valley Transmission Co., St. George	30	Cedar	165	$600	115	50	...	12½	2—
Randolph, Leonardville	30	Cedar	250	...	24	15	...	...	...
					8	15	...	...	...
ATCHISON.									
Atchison Railway, Light & Power Co.									
Troy	35	Cedar	130	550	75	10	60	12–10	...
Lancaster, Effingham, Everest	25	Cedar	140	450	15	10	70	5c wholesale. 10–15c retail.	
					25				
					15	...	...	...	...
Muscotah, Huron	...	...	...	...	15	...	...	...	...
					10	...	...	...	...
BEATTIE.									
Beattie Electric Light Co.									
Home City	25	Cedar	132	300	...	...	50	12½	...
BLUE RAPIDS.									
Marshall County Power & Light Co.									
Marysville	35	Cedar	135	...	25,000 kw. mo.	75	100	12	7-4
Waterville	25–30	Cedar	...	...	4,000 kw. mo.	...	...	5cts. wholesale.	...
Irving	...	Steel	...	...	1,500 kw. mo.	...	...	4cts. wholesale.	...
BONNER SPRINGS.									
Bonner Electric & Manufacturing Co.									
Forest Lake, Edwardsville	...	Wood	...	...	35	...	...	...	...
					15				
Holliday, Wilder	...	...	...	...	10	...	...	...	...
					10				
Basehor	...	Wood	...	250	18	...	60	10c retail	...
Linwood, Eudora	25	Cedar	176	250	28	15	75	10c retail	...
					28	15	60	6c whole.	...
CENTRALIA.									
Corning	25 40	Cedar	130	450	40	20	75	12–10	8·5
Goffs	...	...	...	500	20	...	...	12–10	8·5

* 15c to 5c, with 25 percent off on bills over $5. † 8c to 3c scale.

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Town Served.	Poles. Length (feet).	Poles. Kind.	Poles. Spacing (feet).	Cost per mile.	Transformer, capacity or total load.	Percent motor-load.	Percent of available load captured.	Rates. Lighting.	Rates. Power.
CONCORDIA.									
Gen. Eng. & Man. Co., New York City.									
Jamestown		Cedar			30				
Glasco					65				
Randall		Cedar			17½				
Jewell City					50				
Mankato					50				
Scottsville					17½				
Kackley					20				
Courtland		Cedar			17½				
Formoso					17½				
Scandia					20				
Burr Oak					20				
Simpson		Cedar			10				
Aurora					20				
Clyde					150				
Clifton					60				
Vining									
Palmer					20				
Linn					20				
Greenleaf					60				
Washington					150				
Republic		Cedar			35		85		
Barnes									
Agenda									
Cuba		Cedar							
DODGE CITY.									
Midland Water, Light & Ice Co.									
Ford	30	Steel	300	666	50		100	12½	
Bucklin									
Minneola	30	Steel	375	550	15		90	12½	
Cimarron									
DOWNS.									
Gen. Eng. Mfg. Co., New York City.									
Cawker City	26	Cedar	100–150		60		75	15	
Glenn Elder									

Portis Harlan Gaylord Cedar Claudell Kirwin	26	Cedar	100-150	....	70	....	75	15	....
EMPORIA.									
Hartford Light & Power Co.									
Hartford	25	Cedar	150	....	....	....	50	12·8	....
Neosho Rapids	30	Cedar	150	....	....	....	40	12·8	....
FRANKFORT.									
Vermillion	25	Cedar	....	....	....	35	85	4c whole.	....
GARDEN CITY.									
Garden City Sugar & Land Co.									
Holcomb	22	Steel	375	....	....	Principal load is pumps.	....	3 cents for all purposes.	....
Deerfield	....	....	....	....	....		....		....
Lakin	95	Cedar	132-162	....	....		....		....
GREAT BEND.									
Great Bend Water & Electric Co.									
Hoisington Dent's Spur	25,30,35	Cedar	132	700	240 23	50 5	50	11 to 5c	....
GREENSBURG.									
Johnson Electric Transmission Co									
Haviland	30	Cedar	132	650	....	50	75	7c	....
HIAWATHA.									
Hiawatha Light & Power Co.									
Robinson	25	Cedar	126	450	20	10	75	15c	....
Reserve	25	Cedar	126	500	10	....	50	15c	....
HOLTON.									
Circleville Soldier Havensville	25	Cedar	130	....	15 30 15	50 50 50	75	5¼ to 4½ wholesale.	....
HORTON.									
Whiting Netawaka	25-30	Cedar	132	500	....	....	75	5c whole. 12c retail	....

STATISTICS OF THE TRANSMISSION LAWS OF KANSAS—CONTINUED.

Chief City, Company and Town Served.	Poles.			Cost per mile.	Transformer, capacity or total load.	Percent motor-load.	Percent of available load captured.	Rates.	
	Length (feet).	Kind.	Spacing (feet).					Lighting.	Power.
HUTCHINSON.									
United Water, Gas & Electric Co..									
Nickerson								Wholesale to Nickerson	
Lyons	35–40	Cedar......	200	1,600	900	85	75	10–5	7½–5
Inman	25	Cedar......	200	Over 1,600	130	75	100	12–6	5½–3
JUNCTION CITY.									
Union Light & Power Co.									
Fort Riley	35	Extended top ry. poles	.....	.....	600	.....	.....	5½ 4½	4c
KINSLEY.									
Kinsley Electric Light & Power Co.									
Lewis	30	Steel......	400	600	25	50	80	11–9	6
Belpre	30	Cedar......	250	600	15	50	80	11–9	6
Garfield	.....	Steel......	340	650	30	40	60	15c	.....
KIOWA.									
O. K. Light & Power Co.									
Hardtner	30	Cedar......	250	600	45	15	50	15	7–6
LYNDON.									
Osage County Light & Power Co.									
Quenemo ..... Melvern	25–30	Cedar......	120	375	.....	.....	.....	6	.....
MARYSVILLE.									
Marysville Light, Power & Water Co.									
Herkimer	25	Cedar......	150	.....	50	66	25	15	.....
McPHERSON.									
Farmers; New Gottland Church	30	Cedar......	264	345	25	60	50	10c	.....
OBERLIN.									
Norcatur	25–45	Steel......	300–450	500	20	.....	91	15c	.....

OSKALOOSA.									
Moxley & Co.									
McLouth	30	Cedar	150	....	25	....	....	15-9	....
OTTAWA.									
Pomona	25-45	Steel	250	600	15	....	90	12-6	....
PHILLIPSBURG.									
Phillipsburg Mill & Elevator Co.									
Glade									
Speed	25-30	Cedar	132	750	....	25	....	15	4
Logan									
Agra	25-30	Cedar	150	400	....	....	....	15	4
Stuttgart									
Prairieview	25-30	Cedar	150	400	....	....	....	15	4
Luctor									
Long Island									
PITTSBURG.									
Kansas Gas & Electric Co.									
Mine district	35	Cedar	175	1,600-1,800	800	80	....	9c	7 0.6
Cherokee									
Mines									
Ringo									
Arma	40-50	Cedar	200	2,000	1,000	80	....	Schedule.	....
Franklin									
Frontenac									
Parsons									
Cherryvale	50	Cedar	275	3,000	7,000	80	50	Schedule.	....
Independence	45	Cedar	225	2,000	....	80	80	Schedule.	....
Empire District Electric Co.									
Plants at Lowell and Riverton									
Galena	35	Cypress	132	....	750	95	....	....	....
Baxter Springs									
Columbus									
Weir City	35	Cedar	140	2,000-4,000	4,250	75	....	10	9-1¼
Scammon									
West Mineral									
Mines and railway									
PLEASANTON.									
Pleasanton Electric & Power Co.									
Fulton					20				
Prescott	25	Cedar	140	500	15	5	40	15	10
Hume, Mo.					40				

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

CHIEF CITY, COMPANY AND TOWN SERVED.	Poles.			Cost per mile.	Trans-former, capacity or total load.	Percent motor-load.	Percent of available load captured.	Rates.	
	Length (feet).	Kind.	Spacing (feet).					Lighting.	Power.
PRATT.									
Iuka Preston	25-30	Cedar	125	....	25	....	25	4½ wholesale 15 to consumer	
SABETHA.									
Morrill Hamlin	25	Cedar	125	$400	30	....	60	5c wholesale 12c to consumer	
Fairview Powhattan	30-35	Cedar	125	600	35	....	75	5c wholesale 12½ to consumer	
SENECA.									
Axtell	25	Cedar	125	300	30	....	80	4¼c at switchboard 12c to consumer	
Oneida	25	Cedar	125	300	10	....	90	(as above).	
STAFFORD.									
Zenith Sylvia	25-30	Cedar	132	500	25	20	50	12	6
WELLINGTON.									
City pumps Western Sumner Light & Power Co.	35	Cedar	135	1,200	....	Mostly motor.	....	....	....
Western Sumner Light & Power Co.									
Mayfield Milan Argonia	30	Steel	312	650	40	60	60	15	5-3
Tri-County Light & Power Co.									
Viola Milton Norwich Conway Springs	30	Cedar	250	640	90	50	50	15	7-6

WICHITA.									
Kansas Gas & Electric Co.									
Valley Center									
Sedgwick	50	Cedar	110	2,400	1,050			Schedule.	
Newton									
Halstead									
Benton									
Towanda	45	Cedar	275	1,650	800				
El Dorado									
Burrton	50	Cedar	300		350				
Buhler									
Hesston		Cedar			300				
Moundridge									
Whitewater		Cedar	300						
Augusta	45	Cedar	275	2,500	800	80	33		
El Dorado oil fields									
WILSON.									
Weber Electric Power Co.									
Dorrance	30-35	Cedar	132		50	20	60	15 8	

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Town Served.	Farm service.		Owner, distribution system.	Promoter of line.	Towns with previous service.	Remarks.
	Yes or No.	Desirability.				
ABILENE.						
Riverside Light, Power & Gas Co.						
General office at Abilene.						
Sand Springs						
Enterprise	Yes	Yes	City	City	Enterprise	
Chapman			City	City	Chapman	
Navarre						
Woodbine						
Wakefield						
Detroit						
Talmage						
Manchester						
Longford						
Oak Hill						
Solomon			Com. Co. at Solomon,			
New Cambria						
Central Kansas Power Co.						
Ramona						
Lost Springs						
Lincolnville						
Camp Funston			U. S. Govt. & Co.			
Miltonvale						
Herington to Hope						This line originally built by Hope; later acquired by company.
Central Kansas Power Co. of Gypsum.						
Gypsum to Assaria	Yes	Yes	Assaria	Company		
Riverside Light, Power & Gas Co.					Gypsum	Central Kansas Power Co. connected their lines with Riverside L. P. & G. Co. in 1917, each building part of connecting line.
Bridgeport						
Mentor						
Smolan						
Falon						
Brookville						

Rocky Ford Milling & Power Co. Plant at Rocky Ford, general office Abilene.						
Manhattan	Yes	No	Wholesales power to Manhattan.			The service of Camp Funston brought about junction of this system with that of Abilene.
Ogden						
Fort Riley						
Alma	No	No				
McFarland	No	No				
Kaw Valley Transmission Co., St. George	Yes	Yes	K. V. T. Co	K. V. T. Co.		A "mutual" line—farmers and towns people.
Randolph						
Leonardville						
ATCHISON.						
Atchison Railway, Light & Power Co.						
Troy	Yes	Yes		Company		
Lancaster	Yes	Yes		Company		
Effingham	Yes	Yes		Company		
Everest						
Muscotah						
Huron						
BEATTIE.						
Beattie Electric Light Co.						
Home City	Yes	Yes				
BLUE RAPIDS.						
Marshall County Power & Light Co.						
Marysville	No	No	Marysville Light & Power Company	Company	Marysville	
Waterville	No	No	Waterville		Waterville	
Irving	No	No	Irving			
BONNER SPRINGS.						
Bonner Electric & Manufacturing Co.						
Forest Lake	Yes	Yes				
Edwardsville	Yes	Yes				
Holliday						
Wilder						
Basehor	No	Yes	Company	Basehor		
Linwood			Company			
Eudora	Yes	Yes	Eudora			

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Town Served.	Farm service.		Owner, distribution system.	Promoter of line.	Towns with previous service.	Remarks.
	Yes or No.	Desirability.				
CENTRALIA.						
Corning	No	No				
Goffs	No	No				
CONCORDIA.						
Gen. Eng. & Man. Co., New York City.						
Jamestown	Yes	Yes	Company			
Glasco						
Randall						
Jewell City						
Mankato						
Scottsville						
Kackley						
Courtland						
Formoso						
Scandia						
Burr Oak						
Simpson						
Aurora						
Clyde					Clyde	
Clifton						
Vining						
Palmer						
Linn						
Greenleaf						
Washington						
Republic	Yes	Yes	Company		Washington	
Barnes						
Agenda						
Cuba						
DODGE CITY.						
Midland Water, Light & Ice Co.						
Ford						
Bucklin	No	No	Bucklin	Company	Bucklin	5c cooking rate in all towns served.
Minneola	No	No	Minneola	Minneola		
Cimarron						

DOWNS.						
Gen. Eng. & Mfg. Co., New York City.						
Cawker City	Yes	Yes	Cities	City		
Glenn Elder						
Portis						
Harlan						
Gaylord	Yes	Yes				Company wholesales power to all but two towns.
Cedar						
Claudell						
Kirwin						
EMPORIA.						
Hartford Light & Power Co.						
Hartford	Yes	Yes	Company	Company		
Neosho Rapids	Yes	Yes	Company			
FRANKFORT.						
Vermillion	No		Vermillion			
GARDEN CITY.						
Garden City Sugar & Land Co.						
Holcomb						
Deerfield						
Lakin	Yes	Yes	Company	Company		
GREAT BEND.						
Great Bend Water & Electric Co.						
Hoisington	Yes	No		Company	Hoisington	
Dent's Spur						
GREENSBURG.						
Johnson Electric Transmission Co.						
Haviland	Yes		Company	Company		12c rate to farmers.
HIAWATHA.						
Hiawatha Light & Power Co.						
Robinson	No	No	Company	Company		
Reserve						
HOLTON.						
Circleville						
Soldier	No	Yes	Cities	Cities		
Havensville						

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONTINUED.

Chief City, Company and Town Served.	Farm service.		Owner, distribution system.	Promoter of line.	Towns with previous service.	Remarks.
	Yes or No.	Desirability.				
HORTON.						
Whiting	No	No	Cities	Cities		
Netawaka						
HUTCHINSON.						
United Water, Gas & Electric Co.						
Nickerson			Nickerson			
Lyons	Yes	No	Company	Company	Lyons	
Inman	No	No	Company	Company		
JUNCTION CITY.						
Union Light & Power Co.						
Fort Riley	No	No				
KINSLEY.						
Kinsley Electric Light & Power Co.						
Lewis	Yes	Yes	City	Company		
Belpre	Yes	Yes	City	Company		
Garfield		Yes				
KIOWA.						
O. K. Light & Power Co.						
Hardtner	No	Yes		Company		
LYNDON.						
Osage County Light & Power Co.						
Quenemo	No	Yes	City	Company	Quenemo	
Melvern	No	Yes	City	Company		
MARYSVILLE.						
Marysville Light, Power & Water Co.						
Herkimer	No	No			Herkimer	This company owns line to Blue Rapids. See Blue Rapids.

McPHERSON.						
Farmers: New Gottland Church.	Yes	Yes		Owners		
OBERLIN.						
Norcatur	Yes	Yes	Norcatur	Norcatur		
OSKALOOSA.						
Moxley & Co.						
McLouth	Yes	Yes	Company	Company		
OTTAWA.						
Pomona	No	Yes	Pomona	Pomona		
PHILLIPSBURG.						
Phillipsburg Mill & Elevator Co.						
Glade						
Speed	Yes	Yes				
Logan						
Agra						
Stuttgart						
Prairieview						
Luctor						
Long Island						
PITTSBURG.						
Kansas Gas & Electric Co.						
Mine district	Small consumers					
Cherokee	Yes	Yes		Company	Cherokee	See this company's lines from Wichita.
Mines						
Ringo						
Arma	No	No		Company	Arma	
Franklin						
Frontenac						
Parsons						
Cherryvale	No	No	Company	Company	Cherryvale	Supplies Union Traction Co. at Parsons; 25 cycle line.
Independence	No	No	Company	Company	Independence	Connects Independence plant with sub-station at Cherryvale on preceding line from Pittsburg.
Empire District Electric Co.						
Plants at Lowell and Riverton.						
Galena	No	No	Company	Company		First line in Kansas. Built by Spring River Power Co. Extended on to Joplin, Mo.

STATISTICS OF THE TRANSMISSION LINES OF KANSAS—CONCLUDED.

Chief City, Company and Town Served.	Farm service. Yes or No.	Farm service. Desirability.	Owner, distribution system.	Promoter of line.	Towns with previous service.	Remarks.
PITTSBURG.						
Empire District Electric Co. Plants at Lowell and Riverton—*continued.*						
Baxter Springs						
Columbus						
Weir City						
Scammon	No	No	Company	Company		Empire District Electric Co. lines are interconnected with 25-cycle lines of Kansas Gas & Electric Co. lines above. All Empire lines are 25-cycle.
West Mineral						
Mines and railway						
PLEASANTON.						
Pleasanton Electric & Power Co.						
Fulton						
Prescott	No	No				
Hume, Mo						
PRATT.						
Iuka	Yes			Preston		
Preston						
SABETHA.						
Morrill	No	No	Hamlin, Morrill	Morrill		
Hamlin						
Fairview	Yes	No	Fairview, Powhattan	Powhattan	Fairview	
Powhattan						
SENECA.						
Axtell	No		Axtell	Axtell		
Oneida	Yes		Oneida	Oneida		
STAFFORD.						
Zenith	Yes	Yes	Sylvia	Sylvia	Sylvia	
Sylvia						

WELLINGTON.						
City pumps						
W. S. Light & Power Co	No			City		Built for water supply. Serves power companies west.
Western Sumner Light & Power Co.						
Mayfield						
Milan	Yes	Yes	Company	Company		
Argonia						
Tri-County Light & Power Co.						
Viola						
Milton						
Norwich	No	No	Company	Company		
Conway Springs						
WICHITA.						
Kansas Gas & Electric Co.						
Valley Center						
Sedgwick						
Newton	Yes	Conditionally	Company	Company		See Kansas Gas & Electric Co. lines out of Pittsburg.
Halstead						
Benton						
Towanda			Company		Towanda El Dorado.	
El Dorado						
Burrton						
Buhler			Company			
Hesston						
Moundridge			Moundridge	Company	Moundridge	
Whitewater			Company		Whitewater	
Augusta						
El Dorado oil fields			Company			
WILSON.						
Weber Electric Power Co.						
Dorrance	Yes	Conditionally	Company	Company		

TRANSMISSION LINES IN KANSAS, MAY 1, 1918

BULLETIN OF THE UNIVERSITY OF KANSAS

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BULLETIN No. 3.

DIVISION OF STATE CHEMICAL RESEARCH

W. A. WHITAKER, Director.

A Chemical Survey of the Natural Gases of Kansas and Oklahoma

BY

H. C. ALLEN

AND

E. E. LYDER

ENGINEERING BULLETIN No. 11.

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THE DIVISION OF STATE CHEMICAL RESEARCH.

UNIVERSITY OF KANSAS.

Included in the Department of Chemistry of the University of Kansas is the Division of State Chemical Research, which has for its object the study of those problems of Kansas, municipal or industrial, which may lend themselves to chemical investigation. In addition to its own problems, this division coöperates with other University activities which are engaged in state service work.

The following problems have been studied, or are now in process of investigation:

The Removal of Iron from Municipal Water Supplies.
Sewage Disposal in Kansas.
The Natural Gases of the Mid-Continent Field.
The Physical and Chemical Properties of Kansas Petroleums.
The Coals of Kansas.
The Salt Industry in Kansas.
A Search for Potash in Kansas.
The Conservation of Mineral Wastes by Flotation.
The Softening of Hard Waters.

Correspondence regarding these investigations should be addressed to the Director, Division of State Chemical Research.

PREFACE.

An extensive investigation of the composition of the natural gases of Kansas was completed in 1908 by Professors H. P. Cady and D. F. McFarland of the University of Kansas, and the results of their work were published as chapter VII, volume IX, of the University Geological Survey.

Most of the wells which were sampled and reported in that investigation have ceased flowing, but in the meantime many new wells have been drilled and are now producing. Some of these wells are located in areas that are new as gas-producing fields. In view of this development, and the number of years that have elapsed since the investigation referred to, the Division of State Chemical Research endeavored to obtain representative gas samples from the various fields of Kansas and Oklahoma, and determine their composition and heating values.

While the work on the bulletin was completed early in 1916, it has been impossible to publish it until the present time. However, the data has its value in that it shows the character of the gases in the pools studied, most of which are still producing, and it is hoped that the number included is sufficient to give the reader a good knowledge of the gases which are typical of the two states. This work was carried out by Prof. H. C. Allen and Mr. E. E. Lyder, and their report constitutes Bulletin No. 3 of the Division of State Chemical Research.

W. A. WHITAKER, *Director.*

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PART V.

A Chemical Survey of the Natural Gases of Kansas and Oklahoma.

Part I.

ACKNOWLEDGMENTS.

THE AUTHORS wish to take this opportunity to express their hearty thanks for the assistance rendered by the companies operating in the various fields. Almost without exception, gas companies and gas officials have responded favorably to requests for samples and field data. The importance of such assistance in a work of this character is evident, and the Division of State Chemical Research, under whose auspices this investigation was carried out, joins with the authors in expressing appreciation.

The authors desire to express their appreciation also to members of the staff of the Division of State Chemical Research who assisted in the preparation of this bulletin. Editorial supervision and general preparation of the bulletin for the press were performed by Professor W. A. Whitaker, assisted by Miss Emma Malmberg and Miss Mary Carpenter. The oil and gas maps of Kansas and Oklahoma were prepared by Mr. Frank Farley. Some of the diagrams showing daily variations in gas pressure were obtained by Messrs. A. H. Huisken and F. C. Walters.

INTRODUCTION.

Investigations of the natural-gas problems of the Mid-Continent field have been made at various times by the state geological surveys of Kansas and Oklahoma, and by the United States Bureau of Mines and the United States Geological Survey. These investigations have dealt with geology, economics of production, conservation and waste, future development, and, to a limited extent, with the chemical character and heating values of the gases.

With the increasing difficulties of obtaining a sufficient supply of natural gas, a problem of great importance to the

consumer is that of utilizing efficiently the present supply. The average consumer is accustomed to think of gas in terms of cubic feet, or quantity used, whereas a consideration of the heating value of the gas should be of equal importance. It has been the custom of large corporations for several years to purchase coal on the basis of heating or calorific value. Many corporations in Kansas and Oklahoma and thousands of domestic consumers have used natural gas as a fuel for years, but there is little evidence to show that much consideration has been given to the heating value of the gas, or to variations in this value. A little attention to this subject should convince any consumer that gas should be sold on a heat-unit basis, rather than on the basis of quantity alone.

With the above ideas in mind, it was thought that an investigation such as is detailed herein, and which includes the chemical composition and heating values of gases from the various fields, would be timely and would be of interest to the consumer as well as the technologist.

A few industrial corporations now purchasing gas from local developers buy it on a minimum heat-unit basis. Others, who produce their own gas, are using every effort to make their supply go as far as possible, and fields that formerly were allowed to go to waste are now being pumped under vacuum. In a publication of the Geological Survey[1] in 1906, the Bolton field was said to produce 70,000,000 cubic feet per day, which it was estimated at that time would supply a radius of 150 miles for fifty years. The Bolton field is now almost exhausted, and although Montgomery county is still one of the best of the older fields, it does not furnish enough gas to supply neighboring towns.

Generally speaking, the gases of the Mid-Continent field are good, but not uniform. In a number of localities the gas is of a poor quality, the heating value being so low in a few cases that the gas will not burn. While the consumers are accustomed to attribute all of their gas troubles to low pressure, it is a fact that much annoyance may be caused by variations in the heating value of the gas. Knowing the character of the gas in each field, the pipe-line company should so regulate the amount taken from the different fields as to supply a gas of fairly constant quality.

1. U. S. Geological Survey Bulletin No. 296, 43.

In addition to the above, the chemical analysis of a gas furnishes an indication of its suitability for the recovery of gasoline by the compression or absorption methods, and in some cases may suggest the presence of oil. It is also possible that the accumulation of data of this character may eventually throw considerable light on the very important question of the origin of oil and gas.

In the matter of correlating gas and oil pools and locating new production, a more detailed chemical knowledge is certain to be of great value, and it is very probable that future development will rely upon chemical advice to an increasing extent. Where there has been no development it is manifestly impossible for chemical investigations to be made and conclusions drawn, but with a few wells in a locality producing oil or gas, such an investigation may indicate whether or not a sand is continuous, and the probable direction of future development. A number of cases are known where wells of approximately the same depth and penetrating the same formations, produce a very different product from a chemical standpoint, though the wells are located within one-half mile of each other. This indicates quite clearly that the sand is not continuous.

On the other hand, a chemical investigation may indicate that wells located several miles distant from each other are from the same sand, and that wells located between these may reasonably be expected to be productive.

The above cases are the simplest that may arise, and the number of more complicated ones is unlimited. However, in practically all cases a chemical survey, coupled with a correct interpretation of the results obtained, will furnish information of material value.

The question of the origin of oil and gas has been covered in so many publications that it is not taken up in this bulletin.

HISTORICAL REVIEW OF GAS AND OIL DEVELOPMENT IN KANSAS.[2]

As might be expected, the production of natural gas in Kansas has gone hand in hand with the production of petroleum, consequently the history of the development of these two products will be summarized here together.

In the early pioneer days the presence of so-called tar or oil springs had attracted attention and had been the cause of much discussion among the settlers of the '50s. There were many legends existent at the time concerning the use of these tars and oils by the Indians of the region. The first actual drilling for oil was started in June, 1860, by Dr. G. W. Brown and associates, of Lawrence, who put down a four-inch hole. The location was in Miami county, section 2, township 17, range 24, and the depth of the hole was 100 feet, the full length of the boring apparatus used. This well was nonproductive. Eight miles south another well was drilled, which also proved to be a failure. A third well, located in section 15, township 17, range 23, went to a depth of 275 feet, but the only reward was a thin coating of oil on salt water. The impending Civil War caused operations to be stopped, and the search for oil was not renewed for several years.

In 1873, Colonel Nelson F. Acers sank a well near the town of Iola, Allen county, using a diamond drill and going to a depth of 737 feet. At this point natural gas was encountered and the well started blowing at an estimated volume of 250,000 cubic feet daily. A local company drilled three wells in the same region about this time and obtained good flows of gas. Soon, however, salt water was encountered, and the gas was not utilized.

In 1883, near Paola, Miami county, a company headed by J. W. Werner drilled several wells to about 300 feet and obtained a quantity of gas. A company to supply the town of Paola with natural gas was organized in 1884. One year later, in June, 1885, a well located about eight miles from Paola began an initial daily flow of ten barrels of oil from a depth of 350 feet. This was probably the first oil well of any con-

2. McElwaine, Eugene, "Early Wildcatting in Kansas," Oil and Gas News, Vol. I, Nos. 4-11; 1917. Haworth, Vol. IX, University Geological Survey. Annual reports of the U. S. Geological Survey; and other sources.

sequence in the state. The developments from 1885 down through the following twenty years may be summarized chronologically as follows:

1887. The firm of McBride and Bloom drilled in a few shallow wells, which were small producers, two miles from Paola, near John Brown's mound. Several gas wells were brought in near Osawatomie, Miami county, by W. M. Mills, and the town was piped for gas at that time.

1892. McBride and Bloom, associated with W. M. Mills, drilled the first oil well in southern Kansas on the town site of Neodesha, Wilson county. The oil was found at 800 feet and production began at 50 barrels. The same firm, enlarged to Brown, McBride & Bloom, drilled in a "gasser" near Coffeyville, Montgomery county, which had an initial flow of 5,000,000 cubic feet per day. This was the first big gas well in the Mid-Continent field. This firm also struck gas at Independence, Montgomery county.

1893. McBride & Bloom obtained oil at Independence at 1,180 feet. A flow of 3,000,000 cubic feet of gas was struck at Iola at 840 feet. Guffey & Gayley drilled a score or more of wells in the Neodesha district, which were small producers.

1893, 1894, 1895. Small oil wells were developed at Coffeyville at depths of from 300 to 800 feet. Several big gas wells were drilled in at Iola, some reaching a daily flow of 10,000,000 cubic feet. The Iola field expanded to several square miles and became the largest gas field in the state.

1894. On July 1, 1894, natural gas which had been piped into Neodesha was lighted. The towns of Iola, Coffeyville and Cherryvale began to burn gas in the early '90s. Gas was discovered near Humboldt, Anderson county, and the town was lighted by gas in 1897.

1900. Oil was produced in the Chanute pool, Neosho county.

1901. Oil was discovered at Peru, Chautauqua county.

1902, 1903. A prolific field was opened in Chautauqua county, the sands having a thickness of 48 to 60 feet and being located at depths of 1,100 to 1,200 feet. Oil and gas were discovered at Erie, Neosho county. The Humboldt oil field was opened. A field at North Bolton, Montgomery county, was opened. A big well was brought in north of Chanute, with an initial daily flow of 500 barrels. Several big wells were drilled soon afterward in the same field.

1904. In Montgomery county, the Tyro, Caney and Wayside fields were developed. Paola, Miami county, the original gas field, became a good oil producer.

1905. The Rantoul field, Franklin county, was opened.

1906. Oil development continued near Paola, Osawatomie and Rantoul; also in the Hoffman field, Chautauqua county. Extensive gas developments were carried on south of Independence, Montgomery county.

1907. A gas field was developed southwest of Chanute; another east of Fredonia. Other new gas fields were: southeast of Humboldt; in northeast Chautauqua county; near Cottonwood Falls.

1908. Practically all field development occurred in Oklahoma.

1909. Declining production. New oil wells, 69, located mostly in Chautauqua, Neosho and Allen counties.

1910. Active development in Allen, Chautauqua, Neosho, Montgomery and Wilson counties, owing to an increase in price of oil. New oil wells, about 85.

1911. Development continued in the same districts as in year previous. New oil wells, 172.

1912. Continued development in same counties as in previous two years. A great increase, 536, in producing oil wells.

1913. Greatly increased activity in drilling, led by Montgomery county with 867 wells; Chautauqua, second, with 442 wells; and Neosho, third, with 316. A total of 2,016 wells were drilled in the state, of which number 1,422 produced oil; about 500 produced gas.

1914. An increase of more than 30 percent in output over 1913. Montgomery county again led in activity, followed by Chautauqua (Elgin pool). Butler and Cowley entered for the first time, the last of oil-producing counties. A small well was completed at Piper, in Wyandotte county.

1915. Characterized by the development of the Augusta field in Butler county, and the discovery of the Eldorado field in the same county.

A RESUME OF GAS DEVELOPMENT IN OKLAHOMA.

The development of oil and gas in Oklahoma and Indian Territory was delayed primarily because of the uncertainties in the status of the Indian lands. Government regulations regarding leases were not conducive to development, and the doubtful titles that could be secured to the land made it hazardous for manufacturing concerns to locate there, in spite of the abundance of cheap fuel. Development was also hindered because of a law prohibiting the piping of gas from the state, which eliminated a ready market for the gas. With the removal of these difficulties great development has taken place during recent years.

1906. The Caney well, drilled in February, in the Cherokee Nation, was one of the most spectacular gas wells of the Mid-Continent field. It has a depth of 1,500 feet and is located four miles south of Caney, Kan., one mile from the state line.

1907. Development increased, and 344 gas wells were producing at the end of the year.

1908. Oklahoma ranked fifth in the production of natural gas and seventh in the value of the gas product. About 100 wells out of the 374 were shut in, awaiting a market, most of these wells having been developed unintentionally by producers in their search for petroleum. The development of the industry was retarded on account of the existence of a state law prohibiting the piping of gas out of the state.

1909. The annulment of the state law prohibiting the piping of gas out of the state caused greater activity in the development of the fields. The Quapaw Gas Company constructed a 16-inch line from Washington county, Oklahoma, to Joplin, Mo. Washington, Carter, Comanche, Creek, Kay, Kiowa, Nowata, Okmulgee, Tulsa, Osage, Pawnee, Rogers and Wagoner counties all produced great quantities of gas, with which near-by cities and towns were supplied. The principal gas-producing districts of Oklahoma were the Hogshooter, Collinsville and the Copan. The Hogshooter was the most prolific gas district of the state in this year. Number of gas wells productive at the end of the year, 415.

1910. A considerable quantity of gas was piped out of the state to Kansas and to the Joplin district, Missouri.

1911. The high pressure of gas in the large wells where oil was also produced caused the waste of gas in the small wells. New fields opened in Cherokee, Craig, Latimer, Sequoyah and Le Flore counties.

1912. In the opening of the Cushing oil field in Creek county several good gas wells were completed. Several new gas wells were completed in Kay county also. A new gas field was discovered in Stephens county. Nowata and Washington counties supplied Kansas and Missouri with gas.

1913. The Cushing gas field developed into one of the best in the state. Different methods of drilling caused the conservation of waste gas. Oklahoma was the third state in point of gas production in 1913. Number of productive gas wells brought in during the year, 423.

1914. The Wichita Gas Company completed a 50-mile pipe line from the Cushing field to its compressor station near Bigheart, and began supplying Cushing gas to the Quapaw Company, as well as to its own customers. Developments in Pontotoc county revealed considerable natural gas near Ada. The number of new producing natural-gas wells completed during the year was 388.

1915. Oklahoma at this time supplied gas to the different parts of three other states—Kansas, Missouri and Arkansas. The Shamrock pool, south of the Cushing district, discovered in this year, added a considerable acreage to the productive gas territory in the state. In the southern part of Tulsa county a number of gas wells in the Lost City field were completed in May, and this gas was supplied to Sand Springs across the Arkansas river from Lost City.

STATISTICS OF PRODUCTION.

Well-drilling Record for 1917 in Kansas and Oklahoma.[3]

KANSAS.

WELLS COMPLETED, BY MONTHS.

Month.	*Completed.*	*Oil.*	*Dry.*	*Gas.*
January	171	149	19	3
February	202	197	44	21
March	197	155	36	6
April	208	168	28	12
May	236	189	35	12
June	248	210	26	12
July	318	253	45	20
August	326	243	80	3
September	323	241	57	25
October	445	357	63	25
November	397	311	61	25
December	338	263	65	10
Total	3,469	2,736	559	174

WELLS COMPLETED, BY DISTRICTS.

District.	*Completed.*	*Oil.*	*Dry.*	*Gas.*
Montgomery	443	338	80	25
Chautauqua	336	260	74	32
Butler	1,184	1,015	148	21
Allen	238	229	6	3
Neosho	323	286	25	12
Wilson	187	142	24	21
Miami, Franklin, Douglas	492	354	101	37
"Wild cats"	236	112	101	23
Total, 1917	3,469	2,736	559	174
Total, 1916	3,634	.....	360	127
Difference	168	.....	199	47

OKLAHOMA.

WELLS COMPLETED, BY MONTHS.

Month.	*Completed.*	*Oil.*	*Dry.*	*Gas.*
January	403	325	48	30
February	494	391	71	32
March	344	280	42	22
April	472	356	83	33
May	537	365	127	45
June	533	401	106	26
July	577	467	91	19
August	434	353	69	12
September	645	443	153	49
October	881	656	182	43
November	744	538	156	50
December	612	412	164	36
Total	6,676	4,987	1,292	397

WELLS COMPLETED, BY DISTRICTS.

District.	*Completed.*	*Oil.*	*Dry.*	*Gas.*
Cherokee d. s.	763	648	93	22
Cherokee s. s.	757	674	77	6

3. The Oil and Gas Journal, January 17, 1918.

WELLS COMPLETED, BY DISTRICTS—*Concluded.*

Osage	650	520	61	69
Creek	3,021	2,014	794	213
Cleveland	235	186	44	11
Cushing-Shamrock	343	293	30	20
Kay County	104	74	15	15
Garfield-Noble*	81	61	15	5
Healdton	507	449	44	14
Miscellaneous	215	74	119	22
Total, 1917	6,676	4,987	1,292	397
Total, 1916	7,700	.....	1,136	359
Difference	1,024	.....	156	38

RECORD OF NATURAL-GAS INDUSTRY IN KANSAS, 1898-1915.[4]

YEAR.	Gas produced.		Gas consumed.			Wells.		
	Number of producers.	Value.	Number of consumers.		Value.	Drilled.		Productive Dec. 31.
			Domestic.	Industrial.		Gas.	Dry.	
1898	29	$174,640	*a*6,186	44	$174,640	34	18	121
1899	31	332,592	*a*10,071	71	332,592	44	22	160
1900	32	356,900	*a*9,703	65	356,900	54	15	209
1901	48	659,173	*a*10,227	72	659,173	71	35	276
1902	80	824,431	13,488	91	824,431	144	63	404
1903	120	1,123,849	15,918	143	1,123,849	295	66	666
1904	190	1,517,643	27,204	298	1,517,643	378	135	1,029
1905	171	2,261,836	46,852	601	2,265,945	340	157	1,142
1906	130	4,010,986	79,270	990	*b*4,023,566	331	99	1,495
1907	196	6,198,583	149,327	1,605	*b*6,208,862	361	163	1,760
1908	212	7,691,587	168,855	1,162	*b*7,691,587	403	208	1,917
1909	199	8,293,846	182,657	1,160	*b*8,356,076	452	214	2,138
1910	204	7,755,367	186,333	1,412	*c*9,335,027	392	195	2,149
1911	232	4,854,534	199,523	907	*c*9,493,701	301	152	2,033
1912	253	4,264,706	195,446	1,104	*c*8,521,858	435	200	2,106
1913	305	3,288,394	195,131	950	*c*6,983,802	506	253	2,297
1914	353	3,340,025	187,714	1,079	*b*7,163,746	445	219	2,261
1915	371	4,037,011	201,133	1,4[illegible]6	*b*8,174,289	554	194	2,443
1916	......	....	....	....	....	.....	.....	....

a Number of fires supplied.
b Includes gas taken from Kansas and consumed in Missouri.
c Includes gas taken from Kansas to Missouri; also gas piped from Oklahoma to Kansas and Missouri.

4. Northrop, Mineral Resources of the U. S. 1915. Part II, p. 966.

* Figures represent mark in last six months of the year. Previously the work here had been classed as wildcat.

DEPTH AND ROCK PRESSURE OF WELLS IN KANSAS, 1911-1915.

County.	Depth (feet).	Pressure (pounds). 1911.	1912.	1913.	1914.	1915.
Allen	600–1,500	5–351	10– 300	5– 260	6– 240	5–300
Anderson	230–1,070	60–225	30– 240	65– 250	65– 225	60–225
Bourbon	150– 800	40	40	75	75	80
Chase	64–1,100	1–400	7– 80	3– 95	10–*a*160	6–160
Crawford	100– 640	20– 40	15– 50	40– 50		
Cowley	575–1,500				30– 90	40–176
Chautauqua	300–1,700	25–250	50– 300	35– 410	40–210	25–425
Douglas	350– 450	30,120	10– 280	20– 60		
Johnson	130– 950				10–*a*130	20–610
Ellsworth	950–1,250	....	125– 270	240– 270	160– 250	195–275
Elk	500–1,400	100–235	100	90– 100	75	40
Butler	1,330–1,650	65–450	60–*a*525	550–*a*560	*a*400–*a*600	300–500
Woodson	650–1,150			....	90– 250	200
Greenwood	350– 400	....	....	....	....	....
Labette	320–1,000	25–235	23– 185	20– 240	50– 200	42–195
Linn	85– 750	22–110	6– 70	20– 100	20– 100	10–100
Franklin	300– 720	50–220	3–260	1– 500	50– 240	112
Miami	200– 750				40– 120	45–100
Montgomery	160–1,600	5–350	2–*a*515	5– 700	15– 400	15–175
Morris	600	....	....	....	....	250
Neosho	281–1,200	20–287	28– 250	15– 325	25–*a*360	0–260
Wilson	350–1,350	20–380	15– 380	15– 285	12–*a*350	80–475
Wyandotte	271– 800	40–250	40– 125	30– 125	85	15– 75

a New wells.

RECORD OF NATURAL-GAS INDUSTRY IN OKLAHOMA, 1906-1915.[5]

Year.	Gas produced. Number of producers.	Gas produced. Value.	Gas consumed. Number of consumers. Domestic.	Gas consumed. Number of consumers. Industrial.	Gas consumed. Value.	Wells. Drilled. Gas.	Wells. Drilled. Dry.	Wells. Productive Dec. 31.
1906	50	$259,862	8,391	202	$247,282	81	33	239
1907	107	417,221	11,038	177	406,942	99	41	344
1908	115	860,159	17,567	356	860,159	73	40	374
1909	131	1,806,193	32,907	1,527	1,743,963	97	35	454
1910	168	3,490,704	38,617	1,557	1,911,044	93	58	509
1911	204	6,731,770	44,854	1,507	2,092,603	303	143	732
1912	242	7,406,528	47,017	1,651	3,149,376	329	197	936
1913	347	7,436,389	49,308	1,793	3,740,981	423	298	1,052
1914	437	8,050,039	62,390	1,951	*a*4,226,318	388	182	1,205
1915	434	9,195,804	67,874	1,551	*a*5,058,526	209	118	1,229

a Includes some gas piped from Oklahoma to Missouri.
5. Northrop, Mineral Resources of the U. S., 1915. Part II, pp. 970 and 979.

DEPTH AND ROCK PRESSURE OF WELLS IN OKLAHOMA, 1911-1915.

County.	Depth (feet).	Pressure (pounds).				
		1911.	1912.	1913.	1914.	1915.
Cherokee	600– 650	....	....	....	....	....
Hughes	1,000–2,000	....	200	10– 350	....	500
Carter	590–1,840	48–150	....	....	30– 325	50– 370
Comanche	380–1,000				286– 400	78
Craig	500– 520					
Latimer	1,575–1,600	40–470	....	....	151– 400	....
Sequoyah	1,200					
Creek	400–2,900	20–700	40–850	20– 900	40– 800	40– 400
Kay	436,3,280	40–390	165–365	40– 650	35– 450	50–a1,500
Kiowa	350– 825	10– 50	....	....	30	....
Le Flore	1,300–2,200	300–355	350–355	300– 375	385	140– 350
McIntosh	962–2,740	....	150–600	150– 400	a900	110–a1,200
Marshall	420– 576				150	135– 150
Mayes	106– 640	....	....	....	....	40– 80
Muskogee	800–1,910	18–225	15–350	10– 350	20– 275	20
Nowata	450–1,700	60–450	25–150	25– 300	39– 150	85– 310
Okfuskee	1,450–2,220	....	....	....	a790	a790
Okmulgee	600–2,600	100–700	300	80–a800	80–a840	300–a1,000
Osage	900–2,250	150–650	200–780	100– 700	150–a800	150– 680
Pawnee	1,000–3,150	200–450	40–800	....	....	a860
Coal	400–2,200	....	....	....	110– 425	....
Pittsburg						
Pontotoc	1,000–1,251	....	....	....		
Greer	390	....	....	....	....	....
Payne	2,940–3,150	....	....	....	a800	a900
Rogers	380–1,800	90–480	40–525	25– 500	145– 400	50– 350
Stephens	600–1,200	....	300–325	250– 330	240– 345	263
Tulsa	580–2,200	80–400	50–635	100– 650	70– 525	40– 600
Wagoner	550–1,700	100–300	....	....	165– 405	230– 325
Washington	315–2,260	15–620	10–250	19– 350	25–a635	30– 300

a New wells.

RECORD OF NATURAL-GAS INDUSTRY IN TEXAS, 1909-1915.

Year.	Number of producers.	Number of consumers.		Total value of gas produced.	Wells.		
		Domestic.	Industrial.		Drilled.		Productive Dec. 31.
					Gas.	Dry.	
1909	17	5,035	130	$127,008	7	6	38
1910	19	14,719	133	447,375	22	5	52
1911	29	22,972	303	1,014,945	19	14	69
1912	41	27,226	329	1,405,077	24	23	87
1913	50	37,350	393	2,073,823	43	29	126
1914	75	48,547	468	2,469,770	89	23	197
1915	65	59,386	677	2,593,873	27	30	203

Cities and Towns Supplied with Natural Gas.[6]

KANSAS.

Altamont.
Altoona.
Arkansas City.
Atchison.
Atlanta.
Augusta.
Baldwin City.
Bartlett.
Bassett.
Baxter Springs.
Belle Plaine.
Benedict.
Bentley.
Bonner Springs.
Bronson.
Buffalo.
Buffville.
Burden.
Burlington.
Burrton.
Cambridge.
Caney.
Carlyle.
Chanute.
Chautauqua Springs.
Cherokee.
Cherryvale.
Chetopa.
Coffeyville.
Colony.
Columbus.
Cottonwood Falls.
Coyville.
Deerfield.
Derby.
Douglass.
Earleton.
Edgerton.
Edna.
Edwardsville.
Eldorado.
Elk City.
Elk Falls.
Elm.
Elmdale.
Elsmore.
Empire City.
Emporia.
Erie.
Eudora.
Eureka.
Fairhaven.
Fall River.
Fort Scott.
Fredonia.
Galena.
Gardner.
Garnett.
Gas.
Greeley.
Grenola.
Hackney.
Halstead.
Havana.
Haven.
Hepler.
Howard.
Humboldt.
Hunnewell.
Hutchinson.
Independence.
Iola.
Jefferson.
Kansas City.
Labette.
La Harpe.
Lawrence.
Leavenworth.
Lenexa.
Liberty.
Merriam.
Moline.
Moran.
Mound City.
Mound Valley.
Mount Hope.
Mulvane.
Neodesha.
New Albany.
New Salem.
Newton.
Niotaze.
North Altoona.
Olathe.
Osawatomie.
Oswego.
Ottawa.
Oxford.
Paola.
Parsons.
Peru.
Pittsburg.
Pleasanton.
Princeton.
Rantoul.
Richmond.
Roper.
Rose.
Savonburg.
Scammon.
Scipio.
Sedan.
Sedgwick.
Shawnee.
Spring Hill.
Stanley.
Strong.
Sycamore.
Thayer.
Tonganoxie.
Topeka.
Turner.
Tyro.
Udall.
Valley Center.
Vilas.
Weir.
Welda.
Wellington.
Wellsville.
Wichita.
Winfield.
Yates Center.

OKLAHOMA.

Ada.
Arcadia.
Ardmore.
Avant.
Bartlesville.
Bartlett.
Beggs.
Bigheart.
Bixby.
Blackwell.
Bluejacket.
Boynton.
Braman.
Bristow.
Broken Arrow.
Cameron.
Cathay.
Chandler.
Checotah.
Chelsea.
Choteau.
Claremore.
Cleveland.
Coalton.
Collinsville.
Commerce.
Copan.
Coweta.
Cross.
Cushing.
Davenport.
Dawson.
Delaware.
Depew.
Dewar.
Dewey.
Drumright.
Duncan.
Dustin.
Edmond.
Eufaula.
Garnett.
Gotebo.
Guthrie.
Hallett.
Haskell.
Hattonville.
Henryetta.
Hominy.
Inola.
Jenks.
Jennings.
Kellyville.
Kiefer.
Kildare.
Lawton.
Lenapah.
Locust Grove.
Luther.
Marlow.
Meeker.
Miami.
Midlothian.
Morris.
Mounds.
Muskogee.
Newkirk.
Nowata.
Ochelata.
Oglesby.
Oilton.
Okewah.
Oklahoma.
Okmulgee.
Oologah.
Osage.

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6. Northrop, Mineral Resources of the U. S., 1915, Part II, p. 1007.

Owasso.
Pawhuska.
Ponca.
Porter.
Poteau.
Pryor.
Ramona.
Red Fork.
Red Oak.
Sand Springs.
Sapulpa.
Schulter.
Shawnee.
Skiatook.
South Coffeyville.
Spiro.
Stidham.
Stroud.
Terlton.
Tonkawa.
Tulsa.
Turley.
Vinita.
Wagoner.
Wainwright.
Wann.
Welch.
Wellston.
Whiteagle.
Wirt.
Yale.

NATURAL GAS PRODUCED AND CONSUMED IN UNITED STATES IN 1916.

State.	Produced.			Consumed.		
	Quantity (M cubic feet).	Price (cents per M cubic feet).	Value.	Quantity (M cubic feet).	Price (cents per M cubic feet).	Value.
West Virginia	299,318,907	15.90	$47,603,396	[a]105,104,008	8.19	$8,610,084
Pennsylvania	129,925,150	18.74	24,344,324	201,460,893	17.38	35,015,695
Oklahoma	123,517,358	9.70	11,983,774	[b]93,704,221	7.54	7,062,142
Ohio	69,888,070	22.32	15,601,144	169,480,011	22.06	37,394,410
Louisiana	32,080,975	8.29	2,660,445	[c]32,080,975	8.29	2,660,445
Kansas	31,710,438	15.31	4,855,389	[d]60,564,112	16.07	9,731,518
California	31,643,266	17.19	5,440,277	31,643,266	17.19	5,440,277
Texas	15,809,579	19.89	3,143,871	15,809,579	19.89	3,143,871
New York	8,594,187	29.37	2,524,115	20,594,123	30.26	6,230,826
Illinois	3,533,701	11.22	396,357	[e]3,533,701	11.22	396,357
Arkansas	2,387,935	10.13	241,896	3,347,398	8.59	287,399
Kentucky	2,106,542	35.73	752,635	9,887,956	23.58	2,331,687
Indiana	1,715,499	29.34	503,373	5,021,364	34.78	1,746,285
Wyoming Colorado	575,044	14.97	86,077	575,044	14.97	86,077
Montana	213,315	18.21	38,855	213,315	18.21	38,855
South Dakota Alabama North Dakota	77,478	40.75	31,573	77,478	40.75	31,573
Missouri	69,236	25.41	17,594	69,236	25.41	17,594
Tennessee	2,000	57.50	1,150	2,000	57.50	1,150
Michigan	1,298	73.04	948	1,298	73.04	948
Iowa	275	100.00	275	275	100.00	275
Total	753,170,253	15.96	120,227,468	753,170,253	15.96	120,227,468

a Includes gas piped from West Virginia and consumed in Maryland.
b Includes gas piped from Oklahoma and consumed in Missouri.
c Includes gas piped from Louisiana and consumed in Arkansas and Texas.
d Includes gas piped from Kansas and consumed in Missouri.
e Includes gas piped from Illinois and consumed in Indiana.

GASOLINE EXTRACTED FROM NATURAL GAS AND SOLD IN 1916.[7]

State.	Number of plants.	Quantity (gallons).	Value.	Average recovery of gasoline per 1000 cu. ft. (gallons).
Oklahoma	116	49,079,722	5,942,198	1.968
West Virginia	147	18,765,056	3,025,293	.179
California	26	17,158,754	2,293,822	.691
Pennsylvania	195	9,714,926	1,726,173	.252
Ohio	53	2,638,571	470,804	.485
Illinois	32	2,260,288	262,664	1.688
Louisiana	7	2,113,159	269,564	1.688
Texas	4	1,292,811	201,023	1,363
Kentucky	5	725,467	141,347	.129
Kansas	3	215,000	35,030	.132
New York Colorado	6	249,055	40,283	2.422
Totals	594	104,212,809	14,408,201	.499

7. Northrop, John D., Mineral Resources, U. S. Geological Survey, 1916.

THE ANTICLINE THEORY OF ACCUMULATION.*

Regardless of what may have been the origin of oil and gas and the locations of their formation, there is need of an explanation of how these substances came to accumulate in large bodies relatively near the surface of the earth. Some have attempted to account for it by the so-called crevice theory,[8] which explains the presence of pools by assuming that the oil has ascended through crevices in the stratified rock, at the top of which it has accumulated. Instances of oil accumulation of this kind may be found in the Florence, Colorado, field. When the drill reached the oil-producing horizon in this locality it dropped several feet, apparently through crevices.

Others explain the accumulation by assuming that oil forms along definite lines, or belts, as they are sometimes called. This theory is not entirely without foundation, because in most well-developed fields the production seems to be in a given line, but data show that these lines are, in most cases, parallel to the axes of anticlines.

It is difficult to determine who was the first to propose the so-called anticline theory. In fact, it seems that several geologists in different parts of the world came to somewhat the same conclusion independently. T. Sterry Hunt,[9] it appears, first published an article setting forth the relations between structure and oil deposits. E. S. Anderson,[10] of Marietta, Ohio, and H. Hoefer,[11] of Austria, reached the same conclusions independently of Hunt.

The first to apply the theory was I. C. White, of West Virginia, who succeeded in locating enormous oil and gas pools by applying its principles.

The theory is as follows: Since gas is lighter than oil, and oil is lighter than water, gas will be found at the top, oil next, and water on the bottom, when all are entrapped in the arch of anticlinal fold. If an oil-bearing formation be thus folded it is easily seen how the hydrocarbons would arrange themselves if other conditions were right.

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* Those who are interested in the various theories regarding the origin of oil and gas are referred to "The Data of Geochemistry," by F. W. Clarke, Bulletin 491, U. S. Geological Survey.

8. Bones, J. H. A., Petroleum and Petroleum Wells (1863), p. 13.
9. Canadian Naturalist (1859).
10. Journal of Science (1861).
11. Petroleum Industry of North America, p. 77-80.

It is also evident that the presence of water is necessary for raising the oil and gas into the arches. If it were not present, then we should expect the oil to flow to the bottom of the syncline trough. Ralph Arnold[12] has added important data through his reports on some of the eastern fields. He reports oil in synclines, but accounts for it by stating that the syncline is situated between adjacent anticlines, which are both full of oil; again he reports that other synclines are filled with oil because of the absence of water.

A porous formation is another condition which is necessary for the proper arrangement of the hydrocarbons. This acts as a reservoir for the collection of the hydrocarbons and permits them to flow easily.

An impervious layer must also be situated above the anticlinal folds. This is necessary in order that the oil may not continue to ascend and finally escape.

If any of these conditions are absent the anticlinal theory does not apply. In many cases the striking of dry sands on an anticline adjacent to another that contains petroleum is accounted for by the absence of either an impervious roof or of porous sand. When porous lenticular formations occur the oil is usually collected and held there. In many cases the slope of the surrounding formations is not enough to cause the oil to move along them, and it is therefore found in level sands instead of in anticlinal accumulations. Often oil and gas are found, apparently away from their logical position in the anticline. For instance, both occur far down the sides of it. This apparent irregularity is usually accounted for by small folds or terraces in the side of the formation. These fill, as does the main anticline, with both oil and gas.

Although noticeable exceptions have been found, the anticline theory is the generally accepted explanation of oil accumulation; in Europe it is the universally accepted theory; in Pennsylvania, White has demonstrated its efficiency; Blatchley claims that it is true in Illinois; Arnold reports favorably on it in California; and Hutchinson finds that it holds in Oklahoma and the Mid-Continent field. The great dome formations of Texas and Louisiana are not exceptions to the rule.

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12. Bulletins Nos. 309, 317 and 321 of the U. S. Geological Survey.

PROPERTIES OF NATURAL GAS.

Natural gas is usually reported as being a gaseous mixture of paraffin hydrocarbons, olefin hydrocarbons, hydrogen, nitrogen, and with such impurities as carbon dioxide, carbon monoxide and hydrogen sulphide, but numerous analyses have shown that natural gas has a comparatively simple composition, and that in reality the paraffin hydrocarbons, with carbon dioxide, hydrogen sulphide, nitrogen and some of the rare gases, such as helium, argon and neon, are the only constituents present.

The analyses of various gases listed in this publication show that although the composition of these gases may vary between very wide limits, methane usually predominates. Ethane is present in most gases. The higher hydrocarbons are present in amount usually less than one percent. Some of the wells in Kansas produce gas[13] that consists of as much as 90 percent nitrogen and rare gases. On the other hand, gases in some of the California fields[14] are known to contain as much as 30 percent carbon dioxide. H. P. Cady and D. F. McFarland found that gas from some parts of Kansas contains as much as 1.84 percent helium and other rare gases.

GRAVITY. The specific gravity of a mixed gas depends upon the relative percentages of its constituents. The following table contains the specific gravities of gases usually found in natural gas, together with those of acetylene, ethylene, hydrogen and carbon monoxide, which are present in artificial gases:

NAME.	Formula.	Mo. wt.	Specific gravity.[15] Theoretical.	Specific gravity.[15] Observed.	Observer.	Weight of 1 liter.
Methane	CH_4	16.03	.5539	.5544	Bayme and Perrot,	0.715
Ethane	C_2H_6	30.05	1.0381	1.0494	Bayme and Perrot,	1.3404
Propane	C_3H_8	44.02	1.5204	....	....	1.9659
Butane	C_4H_{10}	58.05	2.0065	2.01	Frankland	2.5414
Carbon dioxide	CO_2	44.00	1.5201	1.52909	Leduc	....
Nitrogen	N_2	28.00	.9680	.96737	Rayleigh	....
Oxygen[16]	O_2	32.00	1.1055	1.10535	Rayleigh	....
Acetylene	C_2H_2	26.02	.613	....	....	....
Ethylene	C_2H_4	28.03	.9676	....	....	....
Hydrogen	H_2	2.016	.0692	....	....	....
Carbon monoxide	CO	28.00	.9671	....	....	....

15. At 0°C. and 760 mm. pressure.
16. Oxygen is frequently present as an impurity due to imperfect sampling.

13. Cady and McFarland, Geological Survey of Kansas, 9, 228 (1908).
14. Burrell, U. S. Bureau of Mines, Bulletin 19, .56 (1911).

The specific gravity of a gas may be calculated from the analysis by using the above data in the following manner:

Constituents.	Sp. gr. of constituents.		Analysis.		
CO_2	1.520	×	0.50%	=	.00076
O_2	1.105	×	0.20	=	.0022
CH_4	0.534	×	90.60	=	.5019
C_2H_6	1.038	×	5.40	=	.0560
Res N_2	0.968	×	3.30	=	.0319

Gravity of gas, air = 1.0............... = 0.5996

The specific gravity of gas is most frequently determined by Bunsen's method of measuring the velocity of the escape of the gas through a small opening and comparing with air under the same conditions.

With all conditions fixed, the squares of the velocities of the gas and air will be very nearly proportional to their respective gravities. Since the actual velocity of the escaping gas determines the time it will take a given volume to escape, the time is measured by means of a stop watch, and these values used in the following equation for calculating the gravity:

$$\frac{S^1}{S_2} = \frac{t^2{}_1}{t^2{}_2}$$

S_1 = specific gravity of gas.
S_2 = specific gravity of air.
t_1 = time of escape of gas.
t_2 = time of escape of air.

Air is considered as the standard or unity in gas gravity calculations and the above equation becomes:

$$S_1 = \frac{t^2{}_1}{t^2{}_2}$$

Illustrating with the gas given above it was found that the time for escape of air from the apparatus was 32.2 seconds, and for the gas 25.0 seconds. Substituting in the equation:

$$S_1 = \frac{t^2{}_1}{t^2{}_2} = \frac{25.0^2}{32.2^2} = \frac{625.0}{103.68} = 0.602, \text{ sp. gr. of gas.}$$

EXPLOSIVE MIXTURES. The Bureau of Mines has determined the explosive limits of mixtures of air and the natural gas of Pittsburg, Pa.[17] Since the composition of this gas is compar-

17. Burrell and Oberfell, U. S. Bureau of Mines, Technical Paper 109.

able to that of other natural gases, its explosive limits when mixed with air will represent in a general way that of other gases.

In a mixture of natural gas and air, the smallest quantity of gas that upon ignition completely burned, as observed by the eye, was 4.92 percent. The largest amount was 11.5 percent.

AIR REQUIRED. One cubic foot of pure methane requires 9.5 cubic feet of air to completely burn it. One cubic foot of natural gas used in Pittsburg required 10 cubic feet of air.

IGNITION TEMPERATURE. The ignition temperature of methane in air is 650° C. to 750° C., and of ethane in air is 520° C. to 630° C. Although no direct data on the subject are at hand, the ignition temperature of a mixture of these gases in the proportion that forms the average natural gas would be from 550° C. to 750° C.

LIQUEFACTION OF GAS. Much interest has been attached lately to the liquefaction products of gases. The condensation of the heavy vapors that are obtained when gas is taken from over oil—"casing-head" or "wet" gases, as they are often termed—has become the basis of a very important industry. Gasoline, the product sought in this industry, is made by submitting these heavy vapors which come from the well under low pressures or vacuum to a process of refrigeration and compression. The product is a series of hydrocarbons ranging from common gasoline to ordinary natural gas.

In discussing the products of the fractionation of natural gas, Allen & Burrell state: "By fractionating natural gas, either during or after liquefaction, four products may be commercially obtained. Roughly these four products may be described as follows: (1) The gaseous product, the common natural gas of commerce; (2) the semiliquid product, known as the new 'wild' product, which should be used only as a liquefied gas, and should be held in high-pressure steel containers only; (3) the liquid product, or light gasoline, used for blending with heavy naphthas; and (4) the heavy product, or ordinary high-grade gasoline."

In brief, the process of making the above products is to pass the vapor, which is drawn from the well at a reduced pressure of 5 to 20 inches of mercury, compress it first to a pressure of from 75 to 80 pounds per square inch, collect the condensate,

and cool the compressed gas with water-cooled coils, and allow it to pass to another compressor, which operates at a pressure of from 200 to 300 pounds per square inch. The gas is cooled and the condensate or light gasoline collected. From here the compressed gas is now allowed to escape from a pipe through a valve and to expand at a much reduced pressure into an outer pipe, incasing the first. This will cause the temperature to drop until the gas liquefies. It will remain a liquid until the temperature is raised or the pressure reduced.

The first product is the high-grade gasoline; the next the light gasoline, which is blended with heavy refinery naphthas and sold for internal-combustion engines; the third, or wild gasoline, is kept in steel cylinders, and the remaining gaseous product is piped away for ordinary fuel purposes.

From the following table it can be seen that it would be useless to compress gases which had no other constituents than methane and ethane. This is true because the pressure at which these gases liquefy is so great that a considerable expenditure of energy would be necessary to liquefy them, and they cannot remain as liquids at ordinary temperatures.

The following table gives some of the properties of ethane, methane and propane, with the idea of presenting their gaseous properties.

The critical temperature is the temperature above which the gas cannot be liquefied, however great the pressure. The critical pressure is the pressure necessary to liquefy a gas at its critical temperature.

PROPERTIES OF SOME OF THE LIGHTER PARAFFINS.*

Name.	Critical temperature, Centigrade.	Critical pressure, lbs. per sq. in.	Liquefaction points.		Boiling point, Centigrade.
			Temperature.	Pressure.	
Methane	81.8	807	—81.8 —95.5	807 735	—160
Ethane	35 34	664 738	35 34	664 738	—93
Propane	94	....	94	647	—45

* From Landholt-Bornstein, Physikalisch-Chemische Tabellen.

Hydrocarbons from C_3H_8 up to C_6H_{14} readily condense at the pressure of the above-described compressor to form either a liquid product at ordinary temperatures or one that can be blended with refinery naphthas as described.

For the so-called "dry" gases the absorption process is being used extensively in the recovery of gasoline. This consists essentially in allowing the gas to come in contact with a heavy hydrocarbon oil, which absorbs most of the higher hydrocarbons that are found in small amounts in many of the gases. The gasoline is then distilled from the heavy oil, which may be used repeatedly. The process makes possible the recovery of a considerable amount of a very high-grade gasoline, that could not be obtained by the compression method.

The following analyses[18] by fractional distillation show the difference in composition of a rather typical "dry" and a "wet" gas, and also the results of the ordinary combustion analysis on the "dry" gas.

	Combustion analysis "dry" gas.	"Dry" gas.	"Wet" gas.
Carbon dioxide	Trace	Trace	Trace
Methane	79.2	84.7	36.8
Ethane	19.6	9.4	32.6
Propane	....	3.0	21.1
Butane	....	*1.3	5.8
Pentane, hexane, etc	....	....	3.7
Residue	1.2	1.6	†........

* Chiefly butane; includes pentane and hexane.
† Residue about one percent.

The following data shows the difference in composition of "dry" gases before and after the removal of gasoline by absorption:

	Fresh gas.		Treated gas.	
	"Low field" gas.	Line L. gas.	"Low field" gas.	Line L. gas.
Carbon dioxide, CO_2	Trace	Trace	Trace	Trace
Methane, CH_4	76.3	83.9	79.7	88.3
Ethane, C_2H_6	18.4	11.7	14.1	7.9
Nitrogen, N_2	5.3	4.4	6.2	3.8
Heating value:				
Gross, 0°C. and 760 mm. pressure, B. T. U.	1,155	1,111	1,111	1,087

Most of the "dry" gases of the Mid-Continental field can be profitably extracted by the absorption method, and the value of the gasoline obtained is much more than the loss in heating values sustained by the gas treatment. Many runs have been made on gases before and after treatment, and the loss in heat

18. U. S. Bureau of Mines, Bulletin 120. Extraction of gasoline from natural gas by absorption methods.

units is usually from 20 to 30 B. T. U. per cu. ft. in the average gas. The gasoline recovered is of the highest quality and excellently adapted to the blending with heavier gasolines to make a satisfactory motor fuel.

METHODS OF DETERMINING THE CONSTITUENTS OF NATURAL GAS.

Carbon Dioxide, CO_2.

In the usual method of analyzing natural gas, carbon dioxide is the first constituent determined. This gas is quantitatively absorbed by strong solutions of potassium hydroxide. The procedure is to pass the gas into a Hempel pipette containing the caustic solution. It is generally sufficient to run the gas into the pipette and back, but to make the determinations uniform throughout the various analyses, the gas was left in contact with the solution for one minute. Where a large percentage of carbon dioxide is known to be present, as after a combustion, the operation is repeated a second time.

The solution used was one recommended by Hempel.[19] One part, by weight, of stick caustic potash is dissolved in two parts of water. Alcoholic potash must not be used.

Higher Hydrocarbons.

By this term is meant gases of the paraffin series C_nH_{2n+2} above ethane; of the series C_nH_{2n}, such as ethylene; of the series C_nH_{2n-2}, such as acetylene; of the series C_nH_{2n-6}, such as benzene. In natural gases the higher paraffins will constitute nearly if not all of the gases grouped under this determination. Although many investigators have reported the presence of members of the olefin series these results are probably due to errors of analyses.

The Bureau of Mines has made very delicate tests for the olefins, but it reports no trace of these gases in the numerous samples examined.

Fuming sulphuric acid or bromine water is usually used to absorb the higher hydrocarbons. Bromine water acts quantitatively only on the the unsaturated hydrocarbons; therefore, in natural gas work, the fuming sulphuric acid is preferable. All members of the paraffin series are more or less soluble in

19. Hempel, Gas Analysis, 201.

this reagent. Anderson and Engelder[20] found that the higher hydrocarbons were taken out, especially the gasoline vapors. R. A. Worstall[21] states that ethane and methane were only slightly soluble and that if gases no higher than these were present, the error due to absorption is negligible. But Gladstone and Tribe,[22] who prepared pure ethane and methane and passed each into pipettes containing fuming sulphuric acid, obtained the following results:

One hundred cubic centimeters of ethane, when passed back and forth into fuming sulphuric acid for two minutes, lost one percent of its volume. At the end of five minutes a contraction in volume of two percent had taken place.

The same was tried with methane, but no contraction took place during five minutes. In gases that contain as much as 20 percent ethane, the error due to absorption of this constituent would be appreciable. In order to further decrease this factor the principle described by Taylor,[23] has been applied.

Taylor found that when 73.5 cubic centimeters of Pittsburg, Pa., natural gas was allowed to stay in contact with 3 cubic centimeters of fuming sulphuric acid for 5 minutes, only .05 cubic centimeters was absorbed. According to Technical Paper 109, Bureau of Mines, this gas usually contains no higher hydrocarbons. Therefore, the error due to absorption of ethane is well within experimental error. The use of a fresh solution each time insures the absorption of the higher constituents, and since only a small percentage is present there is always sufficient acid to absorb all of them.

Therefore, the method used in this work to determine the higher hydrocarbons in natural gas was to agitate the sample for 2½ minutes with 4 cubic centimeters of fuming sulphuric acid, containing 15 percent sulphur trioxde.

The reduction in volume was then measured after sulphur trioxide fumes had been removed by passing the gas into a pipette filled with caustic potash solution.

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20. Absorption of Gasoline Vapors in Natural Gas by Fuming Sulphuric Acid. Journal of Industrial and Engineering Chemistry, 6, 12, 989 (1914).

21. The Absorption of Methane and Ethane by Fuming Sulphuric Acid. Journal of the American Chemical Society, 21 (1899).

22. Notes on the Preparation of Marsh Gas. Journal of the American Chemical Society, X, 45, 154 (1884).

23. An apparatus for the analysis of complex mixtures of gases. Journal of Industrial and Engineering Chemistry, 6, 10, 845 (1914).

Carbon Monoxide, CO.

Many investigators report the presence of carbon monoxide in natural gases, but these results are due probably to errors. However, available data will hardly warrant the statement that no natural gases contain carbon monoxide. Recent work of the Bureau of Mines[24] showed no carbon monoxide in the natural gases used by twenty-five cities in different parts of the United States, and since these city supplies are composed of gases from many wells, these data should have considerable weight.

In the work for this report the samples obtained were not large enough to allow of exhaustive tests on individual wells, but the Lawrence city supply, which is composed of gases from a large number of wells in the Kansas and Oklahoma fields, was tested every day for a period of a week, and at various other times. None of the tests indicated carbon monoxide.

The blood test was the method used for determining carbon monoxide. A brief description follows:

When a dilute solution of pure blood is brought before the slit of a spectroscope two distinct absorption bands, lying between the Fraunhofer lines D and E, are seen. If a reducing agent such as ammonium sulphide is then added to the blood solution, these two bands, which are due to the oxyhæmoglobin of the blood, disappear and are replaced by a single broad and weakly defined band. When carbon monoxide has previously been brought into contact with the blood solution the two absorption bands due to carbon monoxide hæmoglobin do not disappear when the reducing agent is added. Therefore, the persistence of these two lines instead of the appearance of one broad one is decided proof of the presence of carbon monoxide.

The solution is made by freeing a sample of blood from fibrin by either beating it or letting it stand in a cool place for several hours, and then diluting the clear blood with an equal volume of cold saturated solution of borax. The solution used in the test is then prepared by adding 1 cubic centimeter of the concentrated solution to 19 cubic centimeters of water.

The gas was tested by placing about 5 cubic centimeters of the dilute blood solution in a Woulff[25] absorption apparatus, and allowing the gas to bubble through it for about two hours at a rate of about 10 bubbles per minute. The blood is then

24. Burrell and Oberfell. Composition of Gases from Twenty-five Cities. U. S. Bureau of Mines, Technical Paper, 109 (1915).

25. Dennis, Gas Analysis, 228.

transferred to a small test tube or cell and two drops of ammonium sulphide solution added. After allowing the mixture to stand for 30 minutes it is placed before the slit of a spectroscope. The persistence of the two bright lines instead of the appearance of one broad, weakly defined band would show the presence of carbon monoxide.

Small samples may be tested by shaking the gas in a 250 cc. bottle with the blood solution and emptying the blood into a test tube as before. Known samples of gas to which as small a quantity as 0.04 percent carbon monoxide was added gave the test in a way that left no doubt as to the presence of the carbon monoxide.

When a quantitative determination of carbon monoxide was made, the gas was absorbed in either acid or alkaline cuprous chloride. The alkaline cuprous chloride solution was used, since its action on mercury is less than that of the acid. The determination was carried out over mercury, using a fresh solution of cuprous chloride each time.

There are several methods for preparing the acid cuprous chloride, but the one used in this laboratory is commonly known as Sandmeyer's method.[26] In this method 25 parts of crystallized copper sulphate and 12 parts of dry sodium chloride are placed in 50 parts of water and heated until the copper sulphate dissolves. Some sodium sulphate may separate out at this point, but the preparation is continued without the removal of this salt. One hundred parts of concentrated hydrochloric acid and 13 parts of copper trimmings are then added and the whole is boiled in a flask until decolorized. To avoid excessive evaporation it is desirable to insert in the neck of the flask a tall condensing tube or an upright condenser. The addition of platinum foil to the contents of the flask will facilitate reduction. The solution should be kept in bottles that are filled to the neck and are closed by rubber stoppers.

The alkaline solution is prepared from the acid solution by Sandmeyer's method, as follows: 1,200 cc. of the acid solution is poured into 4 liters of water and the resulting precipitate is transferred to a graduated stoppered cylinder of 250 cc. capacity. After about two hours the precipitate and the liquid above the 50 cc. mark is siphoned off and 7.5 percent ammonium hydroxide added up to the 250 cc. mark. The content of the flask is well shaken and allowed to stand for several hours, after which it is ready for use.

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26. Berichte der deutschen chemischen Gesellschaft, 17, 1633 (1884). Dennis, Gas Analysis, 232.

Oxygen, O_2.

The oxygen content of natural gas is a factor which depends almost, if not entirely, on the degree of contamination of the sample. After making due allowance for the hydrocarbons that may be absorbed by the solution used to determine oxygen, and consequently calculated as oxygen, it is doubtful if any oxygen will be found. It would be entirely out of place to say that oxygen did not occur in gas wells or lines, and especially lines where the gas is drawn out under reduced pressure.

The gas taken from the city supply at Lawrence seldom shows over .24 percent oxygen, and this amount means a decrease in volume of .1 of a cubic centimeter on the amount usually taken for analysis. In interpreting the results, therefore, amounts less than this should be regarded with suspicion. In many cases no oxygen is indicated.

The method used was the ordinary pyrogallol method, by which the oxygen was shaken with a strongly alkaline solution of pyrogallol. Hempel prepared the solution by dissolving 120 grams of potassium hydroxide in 80 cc. of water and adding 5 grams of pyrogallol dissolved in 15 cc. of water. According to Hempel, a solution prepared in this way does not give off any carbon monoxide, or at least not enough to appreciably affect the results.

Benedict [27] prepares his solution by dissolving 500 grams of stick potash in 250 cc. of water. The specific gravity of the solution should be 1.55, and if it is not that, caustic or water is added until this gravity is reached. One hundred and thirty cubic centimeters of this solution is added to a solution of 15 grams of pyrogallol dissolved in 15 cc. of distilled water. The solution used in this work was the one recommended by Hempel.

In order that this solution may not come in contact with the air while it is being prepared, the caustic is first made and put in the pipette, after which the pyrogallol solution is added quickly, and the pipette closed. It is also advantageous to run in natural gas over the caustic before adding the pyrogallol. An ordinary Hempel pipette was used for the absorption. This was not mounted on a frame, but was attached to the train of apparatus and suspended so that it could be shaken without removing. The shaking was done by means of a small mechanical shaker.

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27. Composition of the Atmosphere. Carnegie Institution of Washington, Pub. No. 166, 113 (1912).

Methane and Ethane, CH_4, C_2H_6.

These constituents are usually determined by burning the gas, either by explosion or combustion methods, with an excess of oxygen. From the amount of carbon dioxide formed, the contraction, and oxygen consumed, the relative proportions of each are calculated.

The following equations represent, in a chemical way, what takes place when these gases are burned with an excess of oxygen, the products of combustion being in every case carbon dioxide and water:

$$\begin{aligned} CH_4 &+ 2O_2 = CO_2 + 2\,H_2O \\ 2\,C_2H_6 &+ 7O_2 = 4\,CO_2 + 6\,H_2O \\ C_3H_8 &+ 5O_2 = 3\,CO_2 + 4\,H_2O \\ 2\,C_4H_{10} &+ 13O_2 = 8\,CO_2 + 10\,H_2O \end{aligned}$$

Since the coefficients used in the above equations represent very closely the parts by volume of the reacting gases and products, and since the water formed will have a negligible volume, the following equations may be derived from the above:

$$\begin{aligned} CH_4 &= CO_2 = \tfrac{1}{2}\,O_2 = \tfrac{1}{2}\text{ cont.} \\ C_2H_6 &= \tfrac{1}{2}\,CO_2 = \tfrac{2}{7}\,O_2 = \tfrac{2}{5}\text{ cont.} \\ C_3H_8 &= \tfrac{1}{3}\,CO_2 = \tfrac{1}{5}\,O_2 = \tfrac{1}{3}\text{ cont.} \\ C_4H_{10} &= \tfrac{1}{4}\,CO_2 = \tfrac{2}{3}\,O_2 = \tfrac{2}{7}\text{ cont.} \end{aligned}$$

and rearranging—

$$\begin{aligned} &1 \quad CO_2 = CH_4 = 2\,C_2H_6 = 3\,C_3H_8 = 4\,C_4H_{10} \\ &2 \quad O_2 = 2\,CH_4 = 3\tfrac{1}{2}\,C_2H_6 = 5\,C_3H_8 = 6\tfrac{1}{2}\,C_4H_{10} \\ &3 \quad \text{contraction} = 2\,CH_4 = 2\tfrac{1}{2}\,C_2H_6 = 3\,C_3H_8 = 3\tfrac{1}{2}\,C_4H_{10} \end{aligned}$$

From these relations we have the following elementary equations from which the methane and ethane may be calculated:

From CO_2 formed and oxygen consumed—

$$\begin{aligned} \text{I.}\quad CH_4 &= 4\,O_2 - 7\,CO_2 \\ C_2H_6 &= 4\,CO_2 - 2\,O_2 \end{aligned}$$

and from CO_2 formed and contraction—

$$\begin{aligned} \text{II.}\quad 3\,CH_4 &= 4\text{ contraction} - 5\,CO_2 \\ 3\,C_2H_6 &= 4\,CO_2 - 2\text{ contraction} \end{aligned}$$

and from the oxygen consumed and contraction—

$$\begin{aligned} \text{III.}\quad 4\,CH_4 &= 7\text{ contraction} - 5\,O_2 \\ C_2H_6 &= O_2 - \text{contraction} \end{aligned}$$

Then by combining 1 and 3 and solving with 2, we have (T = contraction + CO_2 formed)—

$$\begin{aligned} \text{IV.}\quad 3\,C_2H_6 &= 6\,O_2 - 4\,T \\ 3\,CH_4 &= 7\,T - 9\,O_2 \end{aligned}$$

or, by combining 2 and 3 and solving with 1—

$$\text{V.} \quad CH_4 = B - 3\,CO_2 \quad (B = O_2 + \text{contraction})$$
$$2\,C_2H_6 = 4\,CO_2 - B$$

or, by combining 1 and 2 and solving with 3 —

$$\text{VI.} \quad A = O_2 \text{ used} + CO_2 \text{ formed}$$
$$7\ CH_4 = 11 \text{ contraction} - 5\,A$$
$$7\,C_2H_6 = 4\,A - 6 \text{ contraction}$$

From these relations it can be readily seen that, knowing two factors, the relative amounts of methane and ethane may be calculated.

These calculations give correctly the total percentage of paraffins present, but since only two hydrocarbons can be calculated from the combustion data, when more than two are present, the percentages for the individual paraffins will not be correct.

But assuming that methane and ethane are present in relatively large proportions and that the higher hydrocarbons are present only in small amounts, especially after absorption in fuming sulphuric acid, the calculation to methane and ethane will be very nearly correct. If higher hydrocarbons are present during a combustion the percentage of ethane calculated from the combustion data will be too high and that of methane too low.

The method of calculation used was the one in which carbon dioxide and total contraction are added and used as one factor in the equation and the oxygen consumed as the other (method VI). The advantage of this method is that it eliminates the possible error caused by the absorption of carbon dioxide by the caustic potash solution or water which may get into the line. A very small quantity of the caustic will absorb a relatively large amount of carbon dioxide, and thus cause a considerable error. By using the addition formula, any decrease in CO_2 will make a corresponding increase in the total contraction, and their sum will be the same. This leaves a possible error due to absorption of oxygen by pyrogallol in the line, which is not so likely to take place as the absorption of CO_2 by caustic, because of its slower action and its color, which makes its presence in the line noticeable.

If all the data were absolutely accurate the percentages of methane and ethane should be the same whichever way the cal-

culation is made. An illustration of this is given in the following table. This sample 198-L was calculated six different ways, and the results are quite comparable, though in many cases with quite careful work there may be variations of several percent.

ANALYSIS OF SAMPLES 198-L.
Illustrating the effect of calculating a gas by different methods.

Method.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	B. t. u.
II. CO_2 formed and contraction	....	.50	....	80.73	10.77	7.40	974
I. CO_2 formed and oxygen consumed	....	.50	....	80.58	10.94	7.34	973
III. Oxygen consumed and contraction	....	.50	....	80.32	10.81	7.27	971
IV. (CO_2 + contraction) and oxygen consumed	....	.50	....	80.84	10.77	7.29	973
V. (O_2 + contraction) and CO2	....	....	....	80.70	10.89	7.29	975
VI. (CO_2 + O2) and contraction	....	....	....	80.78	10.84	7.27	975

Nitrogen, N_2.

There are no satisfactory methods for determining nitrogen by absorption or combustion, as in the case of most of the other ordinary gases. It is usually determined as the difference of the original sample after all other gases are determined. This leads to some inaccuracy, because any of the constituents not absorbed or burned will be reported as nitrogen, while Kansas gases are known to contain in some cases as much as 1.84 percent of helium[28] and other gases of the argon group. In the determination made here, all of these inert gases were classed together and called residue. This residue was not determined by difference, or by subtracting all the other constituents from 100 percent, but was found by absorbing the CO_2 and O_2 after the combustion and measuring the residue, then making a correction for the known impurity of the oxygen.

Heating Values.

When methane (CH_4) burns completely to carbon dioxide and water it evolves 23,851 British thermal units per pound or 1,065 British thermal units per cubic foot at 0°C. and 760 mm. pressure. A British thermal unit (B.t.u.) is defined as the heat necessary to raise one pound of water one degree Fahrenheit, usually from 59° to 60°.

The heating value of a gas may be determined by burning a known volume of the gas in a gas calorimeter and noting the

28. Cady and McFarland, The Composition of Natural Gas With Special Reference to Kansas Gas. University Geological Survey of Kansas, IX, 229 (1908).

rise in temperature imparted to a known amount of water, or it may be calculated with a fair degree of accuracy from the analysis by figuring the known heats of combustion of the various gases. The calorimeter method is the more satisfactory when run with proper precautions, but in a gas whose combustible constituents are relatively few and which belong to the same series, as, for instance, natural gas, the method of calculation from the analysis is quite accurate, provided the analysis has been properly made.

In calorimeter work there are usually two heat values determined. "The[29] total heating value of a gas, expressed in the English system of units, is the number of British thermal units produced by the combustion, at constant pressure, of the amount of the gas which would occupy a volume of one cubic foot at a temperature of 60° F, if saturated with water vapor and under a pressure equivalent to that of 30 inches of mercury at 32° F. and under standard gravity, with air of the same temperature and pressure as the gas, when the products of combustion are cooled to the initial temperature of gas and air, and when the water formed by combustion is condensed to the liquid state."

The net heating value of a gas is defined as the number of B. t. u. produced under the above described conditions, when the products of combustion are cooled to the initial temperature of the gas and air, and the water formed in combustion remains in the state of vapor.

The calculated value is made on the gas at 0° C. and 760 mm. pressure. The values used are 1,065 B. t. u. per cubic foot for methane, 1861 for ethane[30] and 2454 for higher hydrocarbons. This value for higher hydrocarbons is used because it is an average of the values for ethane, propane and butane, and perhaps represents rather closely the composition of the constituents absorbed by fuming sulphurc acid.

In the calculation of the so-called lower heating values, the values listed in the table at the end of this section are used. For higher hydrocarbons the value 1,627 was used. This is a value frequently used for artificial gases and is no doubt extremely low for natural gas, but it will occasion little error on account of the low percentage present.

29. Standard Methods of Gas Testing. Bureau of Standards, Circular No. 48.

30. The Bureau of Mines recommends this value instead of 1858. Bulletin 42, 110.

"The net heating value, according to the above definitions, differs from (is less than) the total heating value by an amount of heat equal to the heat of vaporization, at the initial temperature of the gas and air, of the water formed in the combustion of the gas. For most calometric calculations the heat of vaporization of water may be taken as 580 calories per gram, corresponding to 2.3 B. t. u. per cubic centimeter."[30]

The following table contains several heating-value determinations made by the calorimeter and calculated from analyses run on the same samples.

HEATING VALUE OF LAWRENCE CITY GAS AS DETERMINED BY THE CALORIMETER, AND AS CALCULATED FROM ANALYSES.

Date.	Heating value.			
	Calorimeter at 30 in. 60°F.		Gross or higher, calculated from analyses 0°C., 760 mm.	Same calculated to 30 in. and 60°F.*
	Gross.	Net.		
9- 9-15	1,017	919	1,060	1,006
9- 8-15	1,030	939	1,072	1,017
9-15-15	1,027	928	1,074 1,077	1,019 1,022
9-17-15	1,040	946	1,084	1,029
10-19-15	1,005	924	1,067	1,012
10- 1-15	988	911	1,045	992
2- 2-16	974	895	1,017	965

* The calculated heating values are based on the dry gas.

The following table gives the heating values of the usual combustible constituents found in natural and artificial gases:

HEATING VALUES OF GASES.

Name.	Formula.	B. t. u.* per pound.	B. t. u.* per cu. ft. (higher value) at 0°C. 760 mm.	B. t. u.† per cu. ft. (lower value) at 0°C. 760 mm.
Hydrogen	H_2	62,100	348	....
Carbon monoxide	CO	4,476	349	....
Methane	CH_4	23,851	1,065	966
Acetylene	C_2H_2	21,465	1,555	1,846
Ethylene	C_2H_4	21,440	1,673	1,627
Ethane	C_2H_6	22,230	1,858	1,728
Propane	C_3H_8	21,650	2,654	2,477
Propylene	C_3H_6	21,420	2,509	2,385
Butane	$C4H_{10}$	21,330	3,447	....

* Taken from Stillman's Engineering Chemistry, p. 189.
† Taken from Richards' Metallurgical Calculations, part I, p. 31.

30. The Bureau of Mines recommends this value instead of 1858. Bulletin 42, 110.

From the preceding values and the analysis the heating value of a gas is calculated in the following manner:

Analysis.

CO_2	0.50
O_2	0.20
CH_4	90.60
C_2H_6	5.40
Res.	3.30

The carbon dioxide, oxygen and residue are inert, and furnish no heat; the methane, CH_4, and ethane, C_2H_6, being the only constituents of the above gas that are combustible. Then, to calculate the lower, or net heating value:

	B. t. u. per cu. ft.
90.60×966	875.2
5.40×1728	93.3
Heating value of gas	968.5

In case the higher heating value is desired, the respective values for this is used in place of the above values, and if other combustibles are present their percentages are multiplied by the heating values, and the heating values added, for the total heating value of the gas.

Apparatus.

In 1908 Bone and Wheeler [31] described a gas-analysis apparatus in which the various constituents were determined by carrying out the absorptions in a single pipette with fresh solutions for each. The change due to absorption was measured at constant volume by difference in pressure. In 1914 Guy B. Taylor [32] published an article on a piece of apparatus by which the various constituents were determined in a single pipette with fresh solutions. Instead of measuring at constant volume and different pressure, he used the compensating burette, which makes it possible to measure change in volume at constant pressure.

The apparatus used in this work was a combination of the ordinary gas analysis apparatus, in which the various constituents are absorbed in separate pipettes, and of the Taylor type, in which several of the absorptions may be made in one pipette. Figure 1 shows the apparatus which combines the

31. Journal of the Society of Chemical Industry, 27, 10 (1908).
32. Journal of Industrial and Engineering Chemistry, 6, 845 (1914).

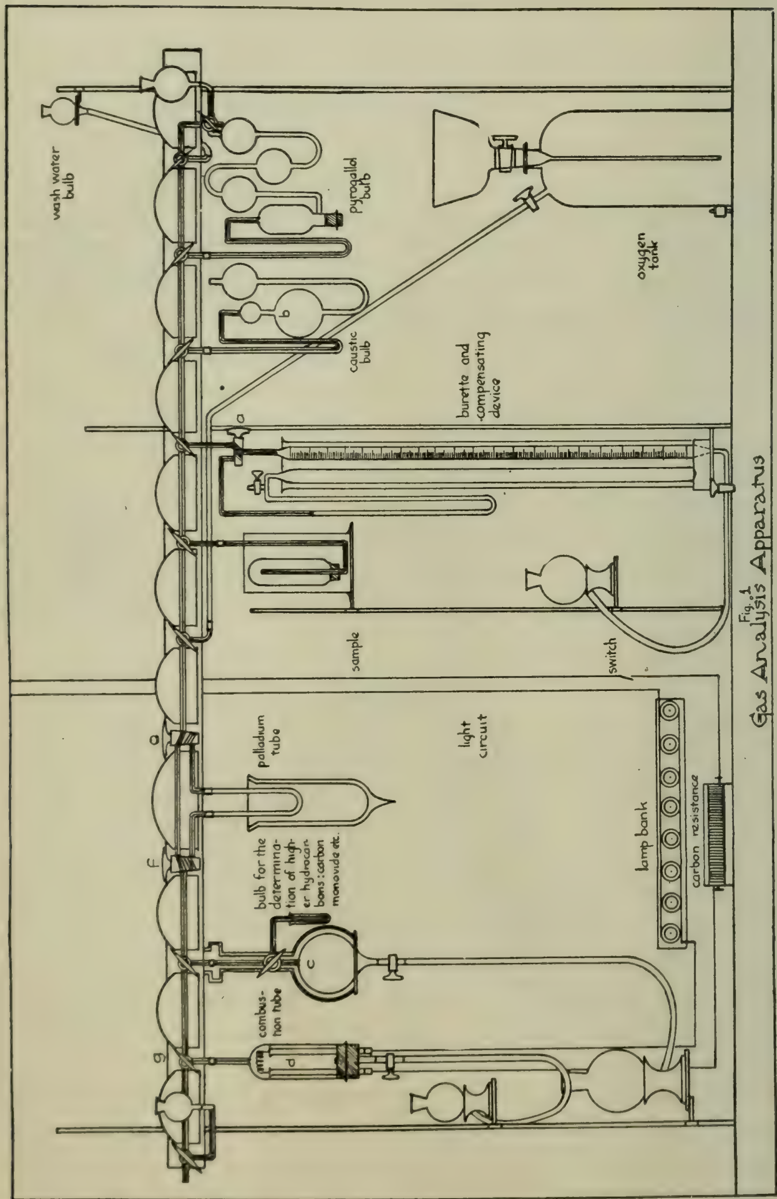

wash water bulb
pyrogallol bulb
caustic bulb
b
oxygen tank
burette and compensating device
a
sample
switch
light circuit
e
palladium tube
f
bulb for the determination of higher hydrocarbons: carbon monoxide etc.
lamp bank
carbon resistance
c
combustion tube
d
g
Fig. 1
Gas Analysis Apparatus

FIG. 1.

compensating burette, the separate bulbs for CO_2 and O_2, the slow combustion tube, the palladium tube for the determination of hydrogen, and the bulb for the determination of higher hydrocarbons, carbon monoxide or any of the constituents absorbed by a liquid which will not affect mercury in the time allowed for absorption. Instead of using a jar set in a wooden trough containing mercury, as is the case of Taylor's apparatus, the apparatus used consisted of a bulb with a three-way stopcock sealed on the top and a separate leveling bulb. The continuous train of absorption bulbs all leading to a direct line from the burette and fitted with a mercury container at each end makes it possible to sweep all of the sample into the burette each time before measuring it. The manometer of the compensating device was calibrated with the burette, and after measuring the sample the mercury was drawn over to the stopcock each time, so that the entire sample was used in the absorptions and combustion.

Since caustic solution will absorb large amounts of carbon dioxide, and the pyrogallol solution will take up considerable quantities of oxygen, a very little of these solutions in the lines will materially affect a determination. To minimize this, the caustic potash and pyrogallol bulbs were arranged on the opposite side of the burette from the other absorption apparatus. This does not permit contact of the sample and the caustic solution before being measured, or of the cxygen and the pyrogallol, nor does it permit the products of combustion to touch either before being measured.

A wash bottle connected in the train permits of easy and frequent washing of the entire apparatus.

Manipulation of the Apparatus.

All the lines, including the tube that leads to the sample bottle and the manometer, are filled with mercury after the vertical tubes leading to the various bulbs have been filled with the solutions. Care must be taken to get as little of the solutions in the line as possible. The sample bottle is opened under water and the sampling tube inserted. Approximately 40 cubic centimeters of the gas is drawn out and the mercury allowed to flow through the line until all the gas is driven into the burette. The stopcock is then turned so as to make connections with the manometer, and the mercury in the manom-

eter is leveled. The burette is then read and the reading recorded as the volume of the sample taken for analysis.

The mercury in the manometer is then drawn over to the stopcock (*a*) and the sample run into the bulb (*b*) containing the potassium hydroxide, and allowed to stand one minute. It is drawn back into the burette and measured again, the decrease being the volume of carbon dioxide present. If a large amount of carbon dioxide is present, it is well to repeat the operation, but the amount found in natural gas is usually taken out quantitatively by one absorption.

The sample is then run into the bulb C, displacing the mercury back into the leveling bulbs. A tube containing 4 cubic centimeters of fuming sulphuric acid is then placed on the side tube of the bulb and the acid drawn in. The bulb is shaken two and one-half minutes and the gas driven again into the bulb B to remove the oxides of sulphur that may be liberated in the reaction. It is allowed to stand in B for three minutes, drawn into the burette, measured and run back into the potassium hydroxide bulb, allowed to stand one minute, and measured again. This process is repeated until there is no decrease in volume after passing it into the caustic. The decrease is the volume of higher hydrocarbons. Time may be saved in this determination by passing the sample back and forth over the caustic instead of simply letting it stand in contact with it. Usually about four successive passages of the gas will suffice to take out all of the sulphur trioxide and sulphur dioxide.

The sample is then passed into the bulb containing the pyrogallol solution and shaken for three minutes. This is usually sufficient to take out the oxygen. The sample is drawn back into the burette and measured. The contraction represents the volume of oxygen.

Should it be desired to determine the carbon monoxide and hydrogen, it is done at this time, as follows:

After the oxygen is removed from the sample it is run again into the bulb (C) and 10 cubic centimeters of cuprous chloride drawn through the side tube. The solution is shaken for five minutes and the sample is drawn back into the burette and measured. The decrease is the volume of carbon monoxide. The bulb should be immediately washed free from the cuprous chloride solution.

Water at a temperature of about 100° C. is placed in the Dewar flask, and when the palladium tube is near 100° the

mercury is driven back through the line to the stopcock (O) and stopcock (F) closed; (O) is then turned to connect the burette with the palladium tube. The pressure is then adjusted so that turning the stopcock (A) from the line to the manometer shows no variation in pressure. Both (O) and (F) are then opened, so as to allow the mercury to flow through the line as before. The gas in the line is then drawn back into the burette and read as the volume of gas to be subjected to the palladium. It is then passed over the palladium from the burette into the bulb (D) and back, at the rate of about 5 cubic centimeters per minute. This is repeated until there is no decrease in volume. The pressure is then equalized in the palladium tube as before and the volume read. The decrease is the volume of hydrogen in the sample.

The palladium is prepared or revived for use by oxidizing the palladium black by heating it to dull redness on a platinum crucible lid in open air, and slowly raising it from over the flame so that it does not cool too quickly.

After the carbon monoxide and hydrogen have been determined, the sample is placed in the pyrogallol bulb, while about 90 cubic centimeters of oxygen is drawn into the burette, measured and run over into the combustion tube (D). The sample is drawn back into the burette and the mercury in the line between the burette and combustion tube drawn back till the oxygen reaches the stopcock (A). The leveling bulb of the combustion tube is placed so that there is almost atmospheric pressure in the combustion tube, and the platinum coil heated to bright redness. The gas is allowed to flow in on the hot wire at the rate of not more than 5 cubic centimeters per minute. Should the mercury flow in on the hot wire it would cause a break, so instead of running the mercury into the combustion tube it is stopped at the stopcock (G), and the sample and oxygen drawn back into the burette till the mercury in the combustion tube nearly reaches the top of the glass tubes carrying the platinum coil. It is passed back and forth into the combustion tube three or four times to insure all of the gas being burned. All of the gas is then run back into the burette and measured, the volume being recorded. It is next run into the potassium hydroxide bulb and left one minute, drawn back into the burette and back into the potassium hydroxide bulb, left for a minute, then drawn back into the burette and meas-

ured. It is passed back through the caustic once more and measured to check the former reading. This reading, when constant, is recorded, and the differences between it and the former one is the carbon dioxide formed during the combustion. The sample is then passed into the pyrogallol bulb, shaken for three minutes, drawn back into the burette, passed back into the bulb again, and shaken for two minutes more. It is then measured and checked, the reading being recorded as the difference between it and the former one being the oxygen remaining unconsumed. The volume left unabsorbed is the residue contained in the sample plus the nitrogen of the oxygen used in the combustion.

Sampling.

About half of the samples analyzed in this investigation and reported in this bulletin were collected and sent in by the companies operating in the field, and the remainder were taken at the various sources by a representative of this organization. Both water and air displacement methods were used, but whenever possible the water-displacement method was advised. Each of these methods has its disadvantages, but where the air-displacement method was followed the men taking the samples usually were unaccustomed to the procedure involved, and frequently the samples contained considerable air.

The following directions for collecting samples were sent out to various companies:

DIRECTIONS FOR TAKING SAMPLES OF NATURAL GAS.

To make sure that the sample of gas is representative of the well, it should be taken at the well, or from the nearest possible opening. If taken at some distance from the well the gas should be allowed to blow for a few minutes before taking the sample.

The magnesium citrate bottles, pop-bottle size, with patented stopper, are convenient for collecting samples, and may be obtained in almost any town. Fill the bottle with water and invert over a pan of water, then collect the gas by bringing the tube beneath the surface of the water and allowing to blow a short time and then inserting the end of the tube into the neck of the bottle and collecting the gas by displacement of the water. The bottle should be closed before removing from the water.

Ordinary bottles of 6 or 8 ounces capacity (about one-half pint) may be used. If a rubber stopper is available it should be pressed firmly into place and tied. If a cork stopper is used the neck of the bottle should

be dipped in melted paraffin after inserting the stopper. A piece of cloth should then be tied over the neck of the bottle, and the whole re-dipped in paraffin.

The air displacement method follows: After removing dead gas by allowing the well to blow a few minutes, attach a rubber tube to an opening as near as possible to well. A bottle (magnesium citrate bottle preferred) is inverted and the rubber tube inserted into it until it reaches the bottom of the bottle. The gas is allowed to blow into the bottle until all of the air is displaced. Usually about three or four minutes is sufficient for the complete removal of the air. The rubber tube is pinched tightly and withdrawn quickly from the bottle. With the bottle still inverted, the stopper is inserted quickly.

The bottles should be plainly labeled in such a way as to make identification certain, and then wrapped with a couple of thicknesses of rather heavy strawboard. They may be sent by parcel post, or if a number of samples are sent it may be desirable to ship them by express.

Gases collected in this way, and with the proper precautions, should show only a trace of air. The advantage of this method is that it affords no opportunity for the water-soluble constituents to be removed; but since, in the present work, the sample was transferred from the bottle to the apparatus by means of water, there was little to be gained through collecting by air displacement.

When magnesium citrate bottles or ordinary bottles with rubber stoppers were used, the samples were not sealed with paraffin while in the field, but they were dipped in paraffin as soon as they reached the laboratory.

The following questionnaire was used in obtaining information regarding the wells from which the various samples were secured:

DIVISION OF STATE CHEMICAL RECORD.

UNIVERSITY OF KANSAS—DEPARTMENT OF CHEMISTRY.

NATURAL GAS SURVEY.

Date.........................., Well or farm name.., No............

Location. twp............, R.............., sec............., quarter............, (or lot)..............................,

Location on sec. or lot, ft. from................N...............E................S.................W, line.

Owner.. Address..

Lessee.. Address..

Driller.. Address..

Record of sands: *ft. to top.* *ft. thick.* *Character of sand.*

1st or.. ....

2d or.. ....

3d or.. ....

4th or.. ....

Total depth of well..........................ft.; diameter..........................., curbing..........................

Date when well was completed.......................................month,...............................Year

Days flowing before being capped...................., Approx. volume....................................cu ft.,

Approximate gas well has delivered to date..cu. ft.,

Open flow: Initial............................cu. ft.; last test....................date;..........................cu ft.,

Rock pressure: Initial........................lbs.; last test........................date;.............................lbs.
(Indicate whether gauged or estimated.)

Character of gas (dry, gas and oil, casing head, etc)..,

Present condition of well...,

Location, distance and direction of other wells within 100 yds..

....

Additional information...

....

....

....

....

(Should include data if gasoline is extracted, etc.)

Data furnished by..of..Company,
(If additional space is required use back of this sheet.)

Laboratory number..,

Sampled by.. Date..,

Sample received.. Analyzed..,

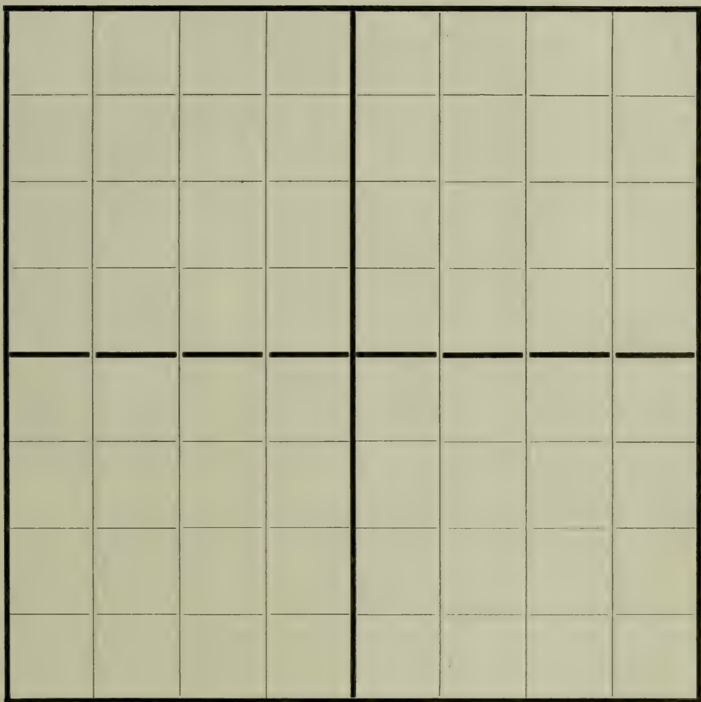
Analysis:	CO_2	HHC	O_2	CO	H_2	CH_4	C_2H_6	Res.	B. t. u.
Percent									

Remarks ....

....

....

....



Indicate location of well in the above diagram of a section.

Sec.....................Range.....................Twp.......................

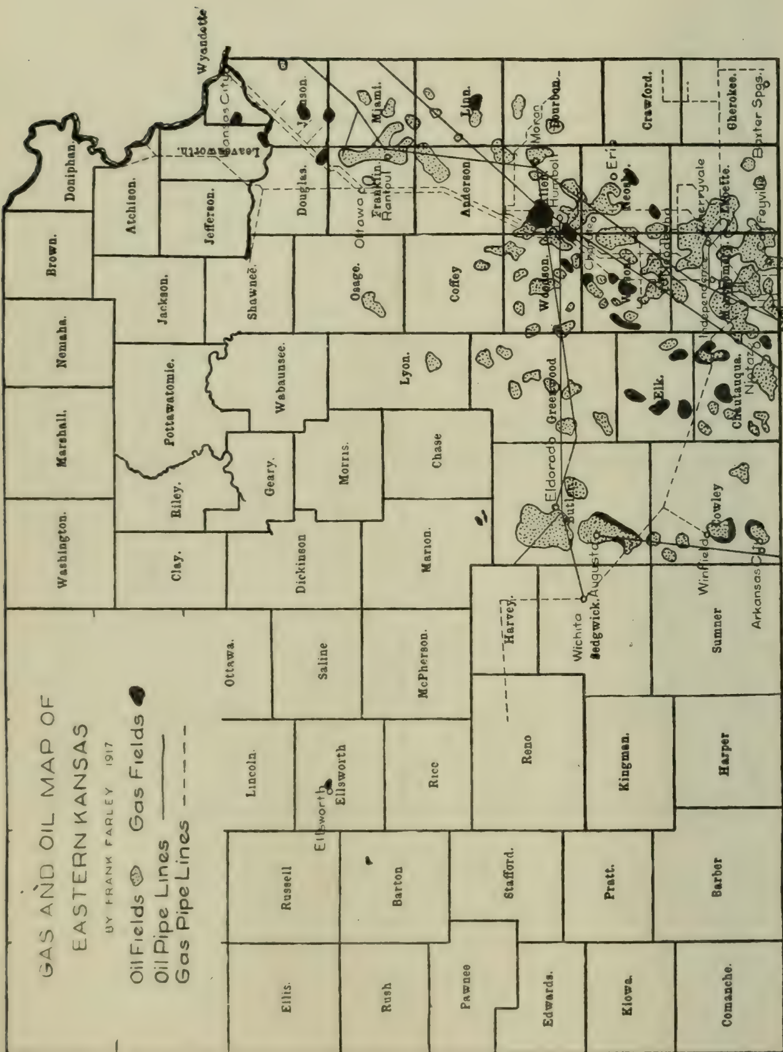

GAS AND OIL MAP OF
EASTERN KANSAS
BY FRANK FARLEY 1917
Oil Fields
Gas Fields
Oil Pipe Lines
Gas Pipe Lines
Wyandotte
Kansas City
Doniphan.
Leavenworth.
Atchison.
Jefferson.
Johnson.
Douglas.
Miami.
Linn.
Bourbon.
Crawford.
Cherokee.
Baxter Spgs.
Brown.
Jackson.
Shawnee.
Franklin.
Rantoul
Ottawa
Anderson
Moran
Humboldt
Allen.
Erie
Neosho.
Cherryvale
Labette.
Parsons
Chanute
Nemaha.
Osage.
Coffey
Woodson.
Wilson.
Fredonia
Independence
Montgomery.
Coffeyville
Pottawatomie.
Wabaunsee.
Lyon.
Greenwood
Elk.
Chautauqua.
Niotaze
Marshall.
Riley.
Geary.
Morris.
Chase
Eldorado
Butler.
Cowley
Washington.
Clay.
Dickinson
Marion.
Augusta
Winfield
Arkansas City
Harvey.
Wichita
Sedgwick.
Sumner
Ottawa.
Saline
McPherson.
Reno
Kingman.
Harper
Lincoln.
Ellsworth
Rice
Russell
Barton
Stafford.
Pratt.
Barber
Ellis.
Rush
Pawnee
Edwards.
Kiowa.
Comanche.

FIG. 2.

Part II.

KANSAS GAS FIELDS AND ANALYSES OF TYPICAL GASES.

The Allen County Field.[33]

THE IOLA FIELD is peculiar in that it is a gas field in which no oil of commercial importance has yet been found. After much unsuccessful prospecting an enormous gas pool was discovered, and development followed. Since no oil is associated with the gas, it is a light, nearly pure methane, with a low residue and almost without odor. Only small amounts of the higher hydrocarbons are found, such as are characteristic of oil-producing regions.

Colonel Acers did the first prospecting for gas at Iola in 1873. He drilled a diamond drill hole 737 feet deep, which produced a little gas and salt water. The next attempt was made by the business men of Iola, who formed a company and were granted a franchise to supply the city with gas. This company drilled three wells west of Iola in the river bottom, one of which produced about 750,000 cubic feet, but this well was spoiled in drilling and flooded with salt water. The company sold out to Messrs. Paullin & Pryor, who drilled four more wells west of town, the last one being good enough to pay for drilling. This preliminary prospecting lasted till 1893. In 1895 Paullin & Pryor drilled a good well, which was piped to town and utilized as a city supply. Their success caused others to begin operations, and as a result the Iola Coöperative Gas Company organized and drilled one of the best wells in the Iola field almost immediately. The new company at once piped its gas into the city, which of course resulted in litigation with Paullin & Pryor, who claimed to have an exclusive franchise. Finally the Paullin & Pryor Company sold out to the Iola Cooperative Company, who supplied the whole town for years.

Other prospectors then opened a field southeast of the city, one well of which produced 7,000,000 cubic feet daily. After drilling several wells they sold out to the Lanyon Zinc Com-

33. Most of the historical account of this field was taken from Haworth, University Geological Survey of Kansas, IX (1908). Now out of print.

pany. About 1900 Iola was producing so much gas that the City Improvement Company was formed. They proposed to furnish any reliable manufacturing company that would locate at Iola free gas for a period of twenty years, if the gas lasted that long. This liberal offer brought many manufacturing companies to the city. Brick plants, zinc smelters, flour mills and many other concerns soon located there. It was not long until the town of Gas, just outside of the city limits of Iola, and LaHarpe, a little farther east, had zinc smelters, brick plants and cement mills.

The pool lay east of the city, in a strip extending 8 to 10 miles east and west and 4 to 5 miles north and south.

The wells were about 800 feet deep, had an initial flow as high as 10,000,000 cubic feet and a pressure of 325 pounds. The enormous drain on this field caused it to decrease quite rapidly, yet it is safe to say that it has produced more gas than any other field in the state. Its importance as a gas-producing area is now insignificant, yet the supply is sufficient for several plants. Some of the zinc smelters were shut down when the gas pressure became so low that the use of gas was not economical, but the European war has increased the price of spelter to such an extent that some of the companies began to use gas again.

Every effort is now being made to conserve the supply and very weak wells are being utilized. Instead of having an initial flow of between 5,000,000 and 10,000,000 cubic feet and a pressure of 325 pounds, the wells now being used have a flow of 500,000 cubic feet or less and a pressure of 150 to 200 pounds. In some cases wells are being used that produce a few thousand feet and with a pressure as low as ten pounds.

The system of pumping and compressing gas from low-pressure fields has made it possible for smelters to use gas from small wells very profitably.

Small wells are now found not only in the old pool, but also around it. Some very good wells have been discovered northwest of Iola. A new field southeast of town, still farther south of the original gas-producing area, was also opened.

Table No. 1 shows the chemical composition of the gases now found in the Iola field.

TABLE No. 1.—The analyses of gases from the Allen county field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat Value, 0° C., 760 mm., B.t.u. Higher.	Heat Value, 0° C., 760 mm., B.t.u. Lower.	Calculated sp. gr. Air=1.
111-L	0.31	....	0.23	92.23	4.06	3.14	1,057.76	961.05	.591
112-L	0.34	.36	....	92.21	3.68	3.39	1,061.28	959.86	.592
113-L	2.08	.05	.02	88.17	6.36	3.32	1,057.40	961.50	.619
114-L	2.32	.20	.24	92.24	1.43	3.54	1,014.91	918.60	.601
117-L	.59	.40	.24	88.48	6.07	4.25	1,067.20	960.05	.612
118-L	.27	.12	.30	89.51	6.05	3.75	1,068.48	971.15	.605
119-L	1.78	.24	.32	88.66	6.01	2.98	1,063.27	964.34	.617
120-L	1.75	....	.54	88.97	3.61	5.12	1,014.80	921.78	.613
122-L	.33	....	.19	88.69	3.48	7.30	1,009.36	916.92	.606
123-L	2.28	.25	.45	89.65	4.86	2.51	1,053.00	949.97	.615
124-L	2.30	.27	.58	88.62	4.42	3.81	1,034.26	936.88	.619
125-L	1.73	.48	.72	90.40	4.42	2.26	1,059.56	957.38	.609
126-L	2.22	.24	.34	90.62	3.67	2.88	1,043.47	942.51	.609
127-L	2.30	.30	.44	90.41	3.86	2.70	1,033.76	947.19	.611
128-L	1.75	.16	.80	92.56	2.59	2.12	1,028.98	941.45	.598
129-L	3.18	.45	.40	89.12	4.04	2.82	1,036.60	938.00	.621
130-L	.74	....	.24	92.60	2.86	3.56	1,039.20	943.90	.590
131-L	.07	....	.34	88.02	1.54	10.02	1,066.00	874.77	.605
131-LL	1.56	.24	.37	90.55	4.21	3.08	1,049.87	947.34	.606
53-L	1.91	.37	.12	91.62	2.83	3.13	....	940.00	....
194	.14	.20	.24	96.50	....	2.92	....	932.00	....

TABLE No. 2.—Data regarding the wells in the Allen county field from which were secured the samples listed in the foregoing table.

LAB. No.	Location. Sec.	Location. R.	Location. Twp.	Farm name.	Well No.	Total depth, feet.	Depth to top of sand, feet.	Thickness of sand, feet.
111-L	32	19	24	Remsburg	1	880	845	35
112-L	20	20	25	Curfman	2	914	840 904	5 10
113-L	22	19	24	Stephenson	1	920	....	....
114-L	5	19	25	Wolf	2	891	838	53
117-L	7	20	25	Ward	1	830	797	25
118-L	18	20	25	Saunders	9	912	822 903	8 9
119-L	9	18	24	Estep	4	....	....	....
120-L	31	19	24	Neff	2	898	860	38
122-L	10	20	26	John Ard	1	665	645	15
123-L	16	18	24	Cline	13	....	....	....
124-L	7	19	24	Anos	1	....	....	....
125-L	13	18	24	Hovvill	1	....	....	....
126-L	22	19	24	Krauger	4	....	....	....
127-L	16	19	25	Crowell	1	937	913	24
128-L	26	19	24	Busley	3	....	....	....
129-L	21	18	24	Lyons	3	800	763	37
130-L	13	19	25	Lyttle	5	798	712 768	20 30
131-L	10	20	26	Zimmerman	2	792	775	12
131-LL	13	18	24	Henderson	1	895	860	35
53-L	5	19	25	Horton	....	....	....	....
194-L	14	19	25	....	....	....	....	....

TABLE No. 3.—Showing the open flow and rock pressure of some typical Allen county wells.

LAB. No.	Open flow.	Date.	Initial rock pressure.	Open flow.	Date.	Rock pressure.
111-L	300,000	....	....	26,000	6- 2-15	5
112-L	550,000	12-19-10	76	103,000	6- 2-15	16
113-L	....	1911	....	70,000	6- 7-15	12
114-L	1,061,245	4-15-09	31	17,560	5- 7-15	....
117-L	500,000	11-1912	175	70,000	5- 3-15	25
118-L	580,000	4-1914	150	103,000	6-23-15	50
119-L	....	1908	....	5,000	6- 8-15	5
120-L	400,000	7-1912	20	50,000	6- 7-15	10
122-L	485,832	2-19-15	190	....	....	....
123-L	....	1907	....	20,000	6- 7-15	5
124-L	....	....	....	50,000	6- 1-15	10
125-L	....	....	....	40,000	6-10-15	6
126-L	....	1911	....	170,000	6- 1-15	12
127-L	350,000	8-1911	148	6,000	6- 2-15	....
128-L	....	....	....	30,000	6- 7-15	11
129-L	13,000,000	5-21-07	200	70,000	6- 9-15	10
130-L	75,000	5-1913	189	26,000	6- 5-15	22
131-L	584,880	2-19-15	150	....	....	....
131-LL	8,000,000	1-1905	296	70,000	6- 9-15	12

The Arkansas City, Cowley County, Field.

In 1905 a small field was discovered and developed in township 34, range 3 and 4, Cowley county, just north of Arkansas City. Gas was found at 700 feet and some of the wells produced as much as 5,000,000 feet daily. One well about six miles north of the city was drilled to a depth of 2,200 feet and gas was found at 620, 1,940 and 1,960 feet. Although some oil mixed with salt water was found at 2,175 feet, not enough was present to justify further drilling.

About forty wells were drilled in the field and half of them were reported as paying. The wells soon became flooded with salt water and at present only one of them is being utilized at all. It furnishes gas for only five houses. The analysis of the gas from this well is as follows:

LAB. No.	Location.			Farm name.	Well	CO_2.	HCC.	O_2.	CH_4.	C_2H_6.	Res.
	Sec.	R.	Twp.								
43-L	18	4	34	T. J. Hess	2	.00	.43	.00	73.28	17.10	9.19

The well is 780 feet deep and has 20 feet of sand. When it was drilled in 1910 the initial flow was about 200,000 feet and the rock pressure was 140 pounds. The last available test, made May 14, 1915, showed a rock pressure of only 40 pounds. It is said that the field is not yet exhausted but the wells are flooded.

If this well could be considered representative of the field it might be possible to correlate the data and determine the direction in which the pools surrounding extended. For instance, about ten miles northeast the partly developed Winfield field is located, and to the southwest the new Arkansas City or Blackwell field. The Winfield gases have a higher residue and lower ethane than the gases from the old Arkansas City well. The gases from Blackwell, which come from a geological horizon comparable to that of the old Arkansas City field, show more characteristics of this gas, such as heating values over 1,000, and high percentage of ethane and lower residue. The field is also characterized by numerous sands in the region southwest. If these analogies are correct, and if it is justifiable to predict from one analysis, we would be led to think that the Blackwell field extended as far as Arkansas City rather than that the Winfield gases and the Arkansas City gases were the same. Then, too, the Winfield gases are more comparable to the Augusta gases than the Blackwell gases.

Deep drillings have uncovered a new and interesting field about 13 miles southwest of Arkansas City, which bids fair to supply a considerable section of this state and Oklahoma for some time to come. The field as now defined lies just across the state line in Oklahoma, with the exception of two or three wells which are in Kansas. Several wells were put down in this new region, but most of them were dry. Among those that struck gas may be mentioned the Horton and Wynn Perkins wells, on the Kansas side; the well just across the line in Oklahoma, known as the School Section 16 well, range 1 east, township 28 north; and farther southwest, the Wolf well on section 16, range 1 east, township 28 north.

The Horton well is 1,514 feet deep and the Wynn Perkins and School Section 16 wells are about the same depth. The difference in the quality of the gas from these three wells is interesting to note. It is generally supposed that these wells are in the same sand, and logs were obtained for both the Wynn Perkins and Horton, but none was secured for the Oklahoma well. Doubtless the two Kansas wells obtain gas from the same sand, but it is certain that the School Section 16 well comes from a different formation. In Table 5, the Horton well shows a heating value of 902 B. t. u. per cubic foot and a residue of 18.34 percent, and the Wynn Perkins well is about

the same. But the School Section 16 well gives 708 B. t. u. and a residue of 32.69. This wide variation could hardly occur in the same sand, and is especially remarkable since the wells are less than three-quarters of a mile apart. The depths of these wells are such that one would expect them to be in the same sand. The Horton well is 1,514 feet; the Wynn Perkins, situated on somewhat higher ground, is 1,540 feet; and the School Section well is 1,530 feet deep. (See logs, p. 54.)

It is not particularly remarkable that the gases should come from different sands, because the region is characterized by numerous producing sands. The peculiarity is in the fact that at comparable depths the gas should be so different.

The dividing line between the Blackwell field and the Arkansas City field is so indistinct that it is difficult to say which wells are in one field and which in the other. In either case the field in which these wells are being located is a new field in itself and should not be confused either with the old Arkansas City field or the old Blackwell field, which extends from the city of Blackwell through range 1 east for six miles north.

One well that deserves special mention in this field, and which has done much to keep development encouraged, is the Wolf well. It was drilled by a Blackwell company organized for the development of deep oil in that section. First, the Swenson well, which was drilled on section 32, range 1 east, township 29 north, to a depth of 3,400 feet, developed to be a good oil well. Then the Blackwell company leased the Wolf land, sank a well, and struck gas that had a flow of approximately 23,000,000 cubic feet at a depth of 3,260 feet. This well flowed 14 days before being capped, and when gauged had a flow of 20,000,000 cubic feet and a pressure of 1,350 pounds per square inch. The Wolf well was finished April 26, 1915.

Between the Wolf well and the Swenson well, another, known as the Alberti well, showed several good producing gas sands. At 260 feet, in an adjoining section, enough gas was struck to drill this well. At about 1,575 feet there was a flow of about 8,000,000 feet, and at 2,600 feet another flow almost as large was found. Such developments seem to justify the investment of considerable capital in the field.

The quality of gas in the region is very good. The sands usually yield a gas that has over 1,000 B. t. u. per cubic foot, but exceptions to this are found in the School Section well and in a 1,500-foot gas in the Alberti well. Gases from deeper

sands are characterized by higher percentages of gases above methane, which increase the heating value per cubic foot materially.

The importance of this new field is realized only when we consider that some of these sands produce so much gas and deliver it at such high pressure that when once tapped it is very difficult to mud off the gas so that drilling may continue for oil. Wells come in from 1,400 to 2,600 feet, which produce 20,000,000 to 50,000,000 cubic feet per 24 hours. An idea concerning the importance of the field may be gained from an abstract of a letter written January 7, 1916, by Mr. W. S. Squires, manager for a local gas company in the field. He says: "There is a stretch running southwest from the Alberti well on section 30 to the Wolf well on section 6, and one well beyond on section 1, where the volume of gas will total something like 235,000,000 cubic feet, counting only the sands that have had the largest volume, and all of them have more or less gas in other sands that I have not taken into consideration in this estimate. This includes about seven or eight wells, at least two of which are 50,000,000-cubic-foot wells."

As would be expected, the gases of these wells issue at an enormous pressure, in some cases as much as 1,400 pounds per square inch.

TABLE No. 4.—The analyses of gases from the Arkansas City field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr.
							Higher.	Lower.	Air=1.
35–L	.05	.10	.11	60.54	6.22	32.97	860	690	.722
36–L	.00	.38	.10	67.36	14.68	17.46	991	908	.701
36–L	.07	.50	.24	65.63	15.30	18.34	984	902	.700
37–L	.29	.67	.41	74.56	17.54	6.50	1,120	1,030	.676
247–L	1.47	.00	.00	36.86	8.91	52.76	562	510	.829
248–L	.00	....	.00	75.52	19.35	5.12	1,110	1,064	.669
9–L	.24	....	....	66.96	12.37	20.42	942	860	.700

TABLE No. 5.—Data regarding the wells in the Arkansas City field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm Name.	Well No.	Depth to sand, feet.	Open flow, in 1,000 cu. ft.	Rock pressure, in lbs. per sq.in.	Date completed.
	Sec.	R.	Twp.						
35-L (Okla.)	16	1E	29N	School Sec. 16	1	1,530	....	....	..1915
36-L (Kan.)	15	2E	35S	Horton	1	1,508	....	....	..1915
36-L (Kan.)	15	2E	35S	Wynn Perkins	1	1,545	6,000	....	1914
7-L (Okla.)	16	1E	28N	Wolf	2	3,270	23,000	1,350	1915
347-L (Okla.)	32	2	29N	Alberti	1	1,500	*8,000	....	....
248-L (Okla.)	32	2	29N	Alberti	1	2,670	*........	....	....
(Kan.)	11	2	....		.....	2,385	6,500	890	1914

*This well came in a 700-bbl. oil well at 3,365 feet.

WYNN AND PERKINS WELL RECORD.

Feet.		Feet.
——	Shale	100
100	Lime, shell	105
105	Shale, black	120
120	Lime shell	122
122	Shale, black	133
133	Lime, shell	140
140	Jyp rock	160
160	Shale, white	175
175	Lime, shell	195
195	Shale, white	220
220	Jyp rock	230
230	Shale, black	255
255	White	300
300	Lime	310
310	Shale, black	320
320	Sand, white	330
330	Red rock	350
350	Shale, white	445
445	Sand	490
490	Little salt, 470 feet	——
490	Red rock	510
510	Brown shale	550
550	Salt, sand, water	590
590	Limestone	610
610	Lime, shells and slate	660
660	Red rock	720
720	Slate	725
725	Red rock	800
800	Black slate	805
805	Limestone	850
	Little gas	830
850	Limestone	870
870	Limestone	885
——	Slate and shells	1,040
1,040	Sand	1,050
——	Water, 1,040 feet	——
1,150	Slate and shells	1,210
1,210	Lime and stone	1,220
1,220	Coal	1,222
1,222	Shells and slate	1,275
——	Water in coal, 1,220 feet,	——
1,275	Lime and stone	1,295
1,295	Slate, shells	1,430
1,430	Limestone	1,435
——	Gas and water	——
1,435	Slate, black	1,460
1,460	Limestone	1,490
——	Hard	——
1,490	Slate, black	1,505
1,505	Sand, water	1,510
1,510	Lime	1,525
1,525	Slate	1,530
1,530	Lime	1,538
1,538	Sand	1,545
	(Six million Gas.)	

HORTON WELL RECORD.

Top of gas sand.................... 1,503 feet.
Bottom of gas sand................ 1,508 feet.
Total depth .... 1,508 feet.

Feet.		Feet.
8	Soil	8
17	Red stuff	25
10	Shell and lime	35
65	Shale, white	110
3	Lime	113
17	Shale	120
70	Lime	190
10	Shale, white	200
5	Lime	205
3	Sand	208
10	Lime	218
10	Shale	228
15	Lime	223
35	Shale	268
52	Lime	320
40	Red shale	360
10	Lime	370
10	Shale, black	380
15	Lime	395
65	Shale, white	460
20	Sand	480
20	Shale, red	500
5	Lime	505
45	Shale	550
10	Lime, water	560
5	Shale, black	565
20	Lime	585
15	Shale	600
20	Lime	620
30	Shale	650
40	Lime	690
103	Shale, red	787
3	Sand, little gas	790
63	Shale	853
15	Lime	868
12	Shale	880
5	Lime	885
10	Shale	895
5	Lime	900
5	Shale	905
10	Lime	915
	Shale, gas	
140	Shale	1,055
5	Lime	1,060
65	Shale	1,125
10	Lime	1,135
65	Shale	1,200
5	Lime	1,205
25	Shale	1,230
20	Sand	1,250
30	Shale	1,280
5	Lime	1,285
50	Shale	1,335
10	Slate	1,345
5	Lime	1,350
30	Shale	1,380
10	Lime	1,390
20	Shale	1,410
50	Shale	1,490
5	Sand, gas	1,495
8	Shale	1,503
5	Gas sand	1,508
	Total	1,508

The Augusta, Butler County, Field.

One of the newest and at present one of the best fields in Kansas is that around the city of Augusta, in Butler county. Augusta has been known as a gas center for several years, but quite recently oil has been found, and now oil is a more important factor than gas. Oil wells have been drilled there that have a production of as much as 10,000 barrels per day.

Operations began in this field in 1906 and 1907, when the city of Augusta drilled a test well and obtained gas for local use. The Wichita Natural Gas Company drilled three wells in 1909, but because development was not successful nothing more was done until 1913, when this company made a geological survey of the region and began developing according to geological advice. Several distinct anticlines were tapped, which suddenly brought Augusta to the front as a gas-producing center.

There seems to be a distinct anticline running almost north and south, extending from a point a mile east of the city to about five miles south. It is in this strip that the "bad" gas of Augusta is found. This gas is encountered at a depth of about 520 feet over an area of about 1,500 acres. Wells usually come in at a volume of about 1,000,000 feet. The quality of this gas is such that it will not burn in air. Analyses show that it contains as much as 87.22 percent residue, of which nearly 2 percent is helium and rare gases. One particular sample, No. 20-L, has a heating value of only 129 B. t. u. per cubic foot at 0°C., 760 mm. Since the gas cannot be used, it is usually mudded off and the well sunk down to a deeper sand, which yields a good gas, of from 940 to 970 B. t. u. per cubic foot.

Another gas-producing area in this locality is in township 27, range 14, section 21, just west of Augusta, where gas is found on the Foster, Carter and Scully leases. The quality of the gas is below the average, running sometimes as low as 719 B. t. u. per cubic foot, with an exceptionally high residue.

South of the city and a little west a series of wells extend through sections 8 and 9, 16 and 17, and 20 and 21, in township 28. All gases analyzed from this locality are of very good quality, except one. This well is on the E. C. Varner lease, section 8, range 4, township 27, and has a heating value of 590 B. t. u. per cubic foot. Records of the well show that the gas

comes from a lime formation above the sand and not from the usual gas-producing sands. The area is characterized by numerous producing sands, one well often having as many as four sands.

The original rock pressure of the field was about 610 pounds, but at present it is considerably less. This gas is delivered into lines for domestic use and transportation out of the field at a pressure of about 260 pounds.

The accompanying tables give analyses of the gases and the characteristics of the wells from which samples were taken.

One of the most interesting wells in the Augusta field is the one drilled on the J. E. Love farm, in section 20, township 28, range 4, by the Wichita Natural Gas Company. While drilling in hard lime at a depth of 1,442 feet, an enormous flow of gas was encountered. The pressure was so great that the tools were lifted entirely out of the well and blown into the air. The well was estimated to produce 23,000,000 feet of gas every 24 hours, and had an initial pressure of approximately 600 pounds per square inch.

This well was supposed to be in a crevice or pocket, and its life was thought to be a question of only a very short time. It was drilled in February, 1915, and is still producing gas. Another well 1,100 feet northeast of it shows none of the characteristics of the former one.

Indications of the crevice formation are in the facts that the well will decrease materially in pressure when being drawn upon constantly, and when left closed the pressure will slowly build up. This is not characteristic of ordinary sand formations.

The gas is about the same quality as other gases in the field. One analysis in March, 1915, showed that the heating value was 993 and another in July gave 1,015 B. t. u. per cubic foot. These analyses would indicate that the quality of the gas was increasing with age.

TABLE No. 6.—The analyses of gases from the Augusta field.

LAB. NO.	CO_2.	HHC.	O_2.*	O_2.†	CH_4.	C_2H_6.	Res.	Heat value. 0°C., 760 mm., B.t.u.		Calculated sp. gr.
								Higher.	Lower.	Air=1.
5-L......	0.17	0.51	0.84	0.00	81.78	10.69	6.84	1,083	983.00	0.640
6-L......	.39	.70	1.39	.00	78.48	13.62	6.79	1,108	993.00	.658
7-L......	.16	.29	.91	.00	76.57	11.84	11.13	1,044	950.00	.662
8-L......	....	....	....	....	....	....	....	....	....	.655
9-L......	.21	.44	1.15	.00	76.48	12.60	10.26	1,061	961.00	.664
10-L......	.11	.30	.67	.00	64.70	8.26	26.62	851	773.00	.708
11-L......	.39	.54	.67	.00	76.65	14.17	8.23	1,094	993.00	.665
12-L......	.32	.15	.49	....	76.09	11.85	11.60	1,035	942.00	.664
13-L......	.12	.28	.55	.00	73.50	12.05	14.03	1,015	922.00	.674
14-L......	.00	.47	.67	.00	79.55	10.36	9.63	1,053	955.00	.649
15-L......	.26	.12	.64	.00	77.44	11.56	10.61	1,043	948.00	.657
16-L......	.48	.47	.23	.23	76.53	11.90	10.39	1,049	928.00	.665
17-L......	.09	.48	.36	.36	73.60	12.19	13.28	1,023	925.00	.675
18-L......	.00	.52	.83	.00	74.50	13.69	11.32	1,062	965.00	.672
19-L......	.47	.47	.91	.00	75.84	13.09	10.13	1,064	966.00	.668
20-L......	.13	.00	.00	.00	10.54	1.64	87.69	143	129.00	.926
70-L......	.00	.00	1.14	.00	66.79	16.51	16.68	1,022	886.00	.703
71-L......	.05	.47	.00	.00	63.48	15.99	19.99	986	897.00	.719
72-L......	.07	.19	.19	.19	63.92	5.67	29.96	791	719.00	.709
73-L......	.19	.29	.46	.46	64.93	20.42	13.72	1,079	984.00	.717
74-L......	.24	.24	.19	.19	69.29	14.45	15.59	1,013	923.00	.694
74-LL.....	.24	.56	.20	.20	68.90	15.37	14.72	1,035	941.00	.698
75-L......	.26	.49	.49	.49	70.95	16.59	11.24	1,077	980.00	.691
76-L......	.29	.33	.29	.29	69.67	15.25	14.16	1,035	942.00	.694
89-L......	.00	.00	2.75	.00	60.10	9.53	30.36	817	745.50	.726
90-L......	.00	.00	.31	.31	50.22	21.32	28.15	932	853.50	.775
91-L......	.00	.00	.50	.50	49.60	21.31	28.59	925	847.00	.778
92-L......	.29	.07	.36	.36	60.22	7.90	31.15	790	718.00	.728
93-L......	....	.19	.41	.41	60.72	6.42	32.26	771	804.00	.722
94-L......	....	....	2.22	.00	76.54	20.00	4.45	1,187	1,084.00	.675
96-L......	.09	.27	....	.00	44.63	9.49	45.50	659	599.49	.792
97-L......	.12	.49	.19	.19	72.30	14.45	12.43	1,052	956.00	.682
98-L......	.13	.13	.58	.00	71.64	18.72	9.37	1,115	1,015.00	.686
99-L......	.13	.62	.60	.00	70.64	17.15	11.43	1,088	958.00	.691
100-L......	.12	.23	.12	.12	72.27	14.29	12.94	1,042	950.00	.683
101-L......	.00	.37	.62	.00	72.94	15.02	11.69	1,066	970.00	.679
102-L......	.00	.36	....	....	71.16	14.47	14.09	1,034	941.00	.685
103-L......	.12	....	.24	.24	72.96	14.81	11.89	1,053	961.00	.673
104-L......	.32	.13	.12	.12	63.32	13.45	22.63	928	844.00	.717
105-L......	.23	.23	.34	.34	68.75	15.46	14.98	1,026	936.00	.697
107-L......	.38	.00	.59	.00	60.19	9.17	30.25	812	748.00	.727
109-L......	....	.71	.14	....	62.15	18.38	18.64	....	930.00	....
8........	.00	.32	.00	....	80.89	3.89	15.27	....	844.00	....
9........	.00	.00	.00	....	8.50	....	....	....	82.00	....

*Shows oxygen present in sample as received.
†Hydrocarbons have been recalculated to air-free basis.

TABLE No. 7.—Data regarding the wells in the Augusta field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Depth to sand, feet.	Thick-ness of sand, feet.	Open flow, in 1,000 cu. ft.	Rock pressure in lbs. per sq. in.
	Sec.	R.	Twp.						
5–L	16	4	28	Ed. Varner	1	1,365 1,430 1,455 1,558	50 17 3 32	1,550	610
6–L	10	4	28	O. Feltham	1	1,449 1,535	6 5	2,800	595
7–L	2	4	28	Jennie Collins	1	546 1,456	....	2,000	600
9–L	26	4	27	S. J. Stafford	1	1,465 1,489	20 26	4,000	600
10–L	21	4	27	Foster	2	....	....	....	....
11–L	20	4	28	J. E. Love	1	1,442	....	23,000	600
12–L	15	4	28	S. G. Purcel	1	....	....	....	....
13–L	2	4	28	N. Brant	1	1,247 1,362 1,444	3 12 30	1,100	555
14–L	25	4	27	A. Skaer	1	....	....	....	....
15–L	35	4	27	A. Palmer	3	....	....	....	....
16–L	20	4	28	Kirkpatrick	1	1,563 1,455	 9	1,400	610
17–L	11	4	28	Wallace	1	1,505 1,540	6 2	2,100	610
19–L	35	4	27	Alvin Palmer	3	1,510	2	1,750	490
20–L	....	....	....	....	....	....	....	....	....
70–L	26	4	27	G. W. Brown	1	....	....	....	....
71–L	23	4	27	Pyton	1	....	....	1,250	....
72–L	28	4	27	Wilson	1	....	....	....	....
73–L	15	4	28	B. Alexander	1	1,452 1,472 1,512	5 10 16	1,500	....
74–L	8	4	28	Geo. Denton	1	....	....	....	....
75–L	16	4	28	W. E. Brown	2	1,375 1,460	....	1,250	....
76–L	11	4	28	Moyle	1	1,225 1,330 1,440	20 15 30	1,000	610
89–L	28	4	27	Carter	1	....	....	....	....
90–L	21	4	27	Foster	2	....	....	....	....
91–L	21	4	27	Foster	3	....	....	....	....
93–L	21	4	27	Scully	1	....	....	....	....
94–L	16	4	28	Frank Varner	2	....	....	....	....
96–L	17	4	28	Ed. Varner	2	*........	....	....	....
97–L	10	4	28	O. Feltham	3	....	....	....	....
98–L	20	4	28	J. E. Love	1	....	....	....	600
99–L	20	4	28	Kirkpatrick	2	1,350	6	2,000	....
100–L	17	4	28	Jim Smith	3	....	....	....	....
101–L	8	4	28	Ralston	2	1,432 1,510	8 15	800	....
102–L	28	4	28	Miller	2	....	....	....	....
103–L	16	4	28	Cunningham	1	1,377 1,458	38 32	350	....
104 L	8	4	28	Marshall	1	....	....	....	....

*Lime formation.

RECORD OF WELL No. 2.
(Sec. 15–28–R4.)

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	4	4	Lime	77	1,086
Slate	30	34	Slate	17	1,103
Gravel	11	45	Lime shells	41	1,144
Slate	207	252	Slate	15	1,159
Lime	40	292	Lime	16	1,175
Slate	53	345	Slate	5	1,180
Lime	30	375	Lime	50	1,220
Slate	15	390	Slate	10	1,230
Slate and shells	65	455	Slate	10	1,250
Sand	12	467	Slate	10	1,260
Lime	14	481	Sand	53	1,313
Slate	50	531	Slate	50	1,363
Slate	45	576	Lime	2	1,365
Shale	61	637	Lime	10	1,375
Slate	33	670	Lime	25	1,400
Slate	40	710	Slate	10	1,410
Lime	15	725	Sand	15	1,425
Slate	7	732	Slate	5	1,430
Slate lime	55	782	Lime	30	1,460
Slate	18	800	Slate	20	1,480
Slate	50	850	Sand	15	1,495
Slate	48	899	Slate	56	1,551
Slate lime	60	959			
Slate	50	1,009	Total depth	....	1,551

RECORD OF WELL No. 1.
(Sec. 20–28–R4.)

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	5	5	Lime	10	790
Lime	40	45	Slate and lime shell	147	937
Slate	15	60	Sandy	15	952
Sand	35	95	Slate and lime shell	198	1,150
Slate	50	145	Lime	70	1,220
Sand	40	185	Slate	20	1,240
Slate	85	210	Lime	20	1,260
Slate	20	230	Slate	10	1,270
Slate	50	280	Slate	30	1,300
Lime	10	270	Slate	8	1,308
Slate	15	305	Lime	12	1,320
Sand	15	320	Slate	40	1,360
Slate	25	345	Broken lime	38	1,398
Slate and lime shell	60	405	Slate	36	1,434
Lime	35	440	Sand	2	1,436
Slate and lime shell	250	690	Sand	6	1,442
Sand	80	770			
Slate	10	780	Total depth	....	1,442

RECORD OF WELL No. 1.
(Sec. 17–28–R4.)

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	2	....	Shale and lime shell	65	1,200
Lime	40	42	Lime	25	1,225
Shale and lime shell	228	270	Lime shell	15	1,240
Sand	20	290	Lime	32	1,272
Shale	160	350	Shale	8	1,280
Lime	20	270	Lime	45	1,325
Shale	10	380	Shale	49	1,374
Lime	25	405	Lime	31	1,405
Shale	65	470	Shale	23	1,428
Sand	5	475	Lime	20	1,448
Shale and lime shell	255	730	Sand	10	1,458
Lime	35	765	Sand	7	1,465
Shale and lime shell	305	1,070	Shale	35	1,500
Lime	25	1,095			
Shale	20	1,115	Total depth	....	1,500
Lime	20	1,135			

RECORD OF WELL No. 1.
(Sec. 10–28–R4.)

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	2	2	Slate	20	890
Lime	60	62	Lime	15	905
Slate	20	82	Slate	20	925
Lime	10	92	Slate, lime shells	65	990
Slate	30	122	Slate	60	1,050
Sand	27	149	Slate	70	1,120
Slate	135	284	Slate	10	1,130
Sand	16	300	Lime	25	1,155
Slate	20	320	Slate	15	1,170
Slate	30	350	Lime	35	1,205
Lime	10	360	Shale	20	1,225
Slate, shells	115	475	Lime	15	1,240
Lime	10	485	Slate	5	1,245
Slate	20	505	Lime	15	1,260
Slate	25	530	Slate	25	1,285
Slate	20	550	Lime	15	1,300
Slate	5	555	Lime	45	1,345
Slate, lime, shells	55	610	Slate	57	1,402
Sand	10	620	Lime, sandy	35	1,437
Slate	50	670	Slate	21	1,458
Slate	20	690	Lime, sandy	26	1,484
Slate	10	700	Slate	3	1,487
Sand	10	710	Sand	16	1,503
Slate	40	750	Shale	7	1,510
Lime	47	797	Sand	20	1,530
Slate	15	812	Sandy shale	50	1,580
Lime	6	818	Sandy shale	29	1,609
Slate	32	850			
Slate	20	870	Total depth	....	1,609

The Chanute, Neosho County, Field.

Chanute has long been known as an oil and gas town, and the rise and fall of its production may be found listed in other publications.[34] It is unfortunate that a complete set of data concerning it is not now at hand, but this is rather difficult to obtain, owing to the fact that several small companies are the producers, and some of the wells are very old, and records are lost. Table No. 8 gives the analyses of some of the gases.

34. University Geological Survey of Kansas, Vol. IX (1908).

TABLE No. 8.—The analyses of gases from the Chanute field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr. Air=1.
							Higher.	Lower.	
201-L (*a*)	1.42	0.29	....	92.90	2.06	3.32	1,035	938	0.594
202-L (*b*)	.54	.24	....	94.56	.80	3.84	1,028	930	.581
203-L (*c*)	1.23	....	.36	92.62	2.93	2.86	1,041	945	.594
204-L (*d*)	1.40	.27	.24	96.03	.39	1.67	1,037	939	.580
206-L (*e*)	.55	.55	.27	89.15	4.71	4.77	1,052	952	.609
207-L (*f*)	.73	.24	.02	90.86	2.91	5.23	1,028	932	.599
205-L	.63	.46	.34	91.25	2.98	4.34	1,039	940	.599

(*a*) Taken from the Young lease, three and one-half miles northwest of Chanute.
(*b*) Taken from the Schwetzer farm, five and one-half miles northeast of Chanute.
(*c*) This is a composite sample from four wells on the McMinsing lease, about six miles southeast of the city. Sample taken at meter station.
(*d*) Sample from several wells about six miles southeast of Chanute. Sample taken at meter station.
(*e*) The M. E. Cross No. 1 and 2 southeast of Chanute. Taken at meter station in Chanute.
(*f*) Composite sample taken from meter station at old glass plant, Chanute, ten wells in Turkey creek field, south of town.

Seven samples were taken from around the city of Chanute; all of these wells, and others, of which the samples are representative, furnish the city with gas. Another sample was taken from the city hall on the same day. It will be noticed (see table No. 17) that the average of the seven samples from the field is 938 B. t. u. per cubic foot, while the sample taken from the city hall (No. 205-L) shows 941 B. t. u.

The Chautauqua County Field.

Gas is found in varying quantities in ranges 10, 11 and 12 and throughout townships 33 and 35. In 1913 a very productive field was opened in sections 23, 24, 25, 26 and 36, in township 33 south and range 10 east. Since that time wells have been drilled in different parts of the county. For instance, a well was brought in on section 27, range 12, township 33, which had a daily flow of 3,750,000 cubic feet. The gas sometimes occurs with oil, but usually the oil and gas sands are separate.

The wells in this region, from the sands about 700 feet deep, come in at about 5,000,000 cubic feet, open flow, and at about 300 pounds rock pressure. Other sands are found in the region, however, which range in depth from 320 to 1,300 feet, and which produce gas in commercial quantities.

One feature of special note about this field is the variation in quality of the gas produced there. From table No. 9, it can be seen that there are gases ranging from 459 to 960 B. t. u.

per cubic foot. Gases found above 700 feet deep are, as a rule, very poor, running from 450 to 560 B. t. u., and even this class may be divided still farther into those that are quite shallow and have a heating value of about 450, and those from 700 feet or lower depths reaching 550 B. t. u. Gases from lower depths increase in combustible constituents up to a type like No. 68-L, Table 17, which reached 959 B. t. u.

TABLE No. 9.—The analyses of gases from the Chautauqua county field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr. Air=1.
							Higher.	Lower.	
65	0.24	....	0.32	38.94	4.80	55.70	504	458.90	0.812
66	.45	.27	.50	63.68	5.69	29.39	791	717.00	.713
67	....	....	.38	45.13	6.82	47.65	706	551.00	.786
68–L	.35	.65	.50	67.15	17.35	14.00	1,055	959.00	.708
69–L	....	.24	.60	44.02	6.06	49.05	588	534.00	.792
80–L	.12	.50	.24	70.06	8.91	20.15	925	840.00	.688
83–L	.33	.26	.86	67.16	14.87	16.53	998	908.00	.705
84–L	.32	....	.27	66.39	13.75	19.26	963	879.00	.705
193–L	.19	.26	.94	85.17	2.42	10.99	959	868.00	.620
238–L	....	....	.37	47.40	2.95	49.28	560	508.00	.774
239–L	....	....	.37	44.58	3.27	51.78	546	486.00	.786
43	.14	.00	.55	48.39	3.86	47.06	587	534.00	.770
44	.00	.00	.56	41.46	9.63	48.36	621	566.00	.804
46	.00	.00	.40	49.08	3.89	46.67	595	541.00	.768
47	*.00	.00	.36	40.92	9.85	48.75	619	565.00	.805
50	.00	.001	.15	41.65	7.61	49.60	585	534.00	.803
52	.27	.00	.27	43.19	7.85	48.43	606	553.00	.797
55	.00	.00	.56	43.96	6.07	49.41	581	530.00	.791
57	.00	.002	.04	39.38	7.16	51.42	553	504.00	.813
59	.00	.00	.14	43.71	7.89	48.27	612	558.00	.793
2	.30	.00	.18	42.38	1.85	55.29	486	441.00	.795

TABLE No. 10.—Data regarding the wells in the Chautauqua county field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Depth, feet.	Thickness of sand, feet.	Open flow, 1,000 cu. ft.	Rock pressure, in lbs. per sq. in.	Date completed.
	Sec.	R.	Twp.							
65–L	27	11	33	Wadsworth & Fleming	1	320	18	1,000	125	4–15
66–L	26	11	34	Thornhill	2	876	6	500	225	11–13
67–L*	......	......	......	......	......	......	......	......	......	......
68–L	26	11	34	Brown	2	1,204	19-	1,000	300	11–12
69–L	14	10	34	Graham	1	730	15	2,500	225	5–15
80–L	12	10	35	......	......	800	......	......	230	......
83–L	11	12	35	......	......	......	......	1,500	404	1915
84–L	14	10	34	......	......	1,300	......	2,000	......	1915
193–L	27	12	33	Sharp	1	......	......	3,750	......	1915
238–L	14	10	34	Graham	1	......	......	......	......	......
43	14	10	34	Graham	2	......	......	......	......	......
239	25	10	33	Butcher	1	......	......	......	......	......
44	24	10	33	Holroyd	7	390–40	......	......	......	......
46	25	10	33	Barr	1	......	......	......	......	......
47	24	10	33	Holroyd	1	......	......	......	......	......
48	24	10	33	Gray	1	340–20	......	......	......	......
50	......	......	......	Bovaird	1	......	......	......	......	......
52	36	10	33	Sipple	2	......	......	......	......	......
55	36	10	33	Butcher	1	......	......	......	......	......
57	27	10	33	Holroyd	6	......	......	......	......	......
59	24	10	33	Holroyd	2	......	......	......	......	......
2	35	10	33	......	......	800	......	......	......	......
113	35	10	33	......	......	......	......	......	......	......

*Sample submitted by Bell Bros., McDonald.

The Eldorado, Butler County, Field.

While the Eldorado field is noted as an oil-producing field, there is considerable gas encountered in drilling for oil. This gas is usually mudded off, since the oil is much more valuable, but some of the gas is being utilized.

The following analyses, data and tables have been furnished by the Empire Gas and Fuel Company, of Bartlesville, Okla.

A noticeable feature of these gases is their high percentage of residue, also in some cases the rather high ethane content. The wide variation in composition and heating value is also unusual, and none of these gases would be considered a typical natural gas.

TABLE No. 11.—Analyses of gases from the Eldorado field, Butler county.

NAME OF LEASE.	CO_2.	O_2.	CH_4.	C_2H_6.	Res.	Lower heat value, 0° C., 760 mm., B.t.u.
Stokes, No. 3	0.56	0.00	54.58	3.33	41.53	584
Gussman, No. 1	.19	.00	60.68	3.22	35.95	642
Boyer, No. 4	.15	.45	57.64	4.29	37.47	631
Barnhill, No. 2	.06	.50	56.60	7.35	35.48	674
Howe, No. 23	.10	.14	62.68	11.82	25.26	811
Boyer, No. 1	.31	.20	61.39	4.65	33.45	674
Robison, No. 23	.21	.00	48.79	21.59	29.41	845
J. A. Shumway, No. 1	.12	.39	59.16	11.50	28.82	771
H. Adsit, No. 3	.12	.12	31.36	12.78	55.64	524

All leases are owned by the Empire Gas and Fuel Company, excepting Shumway, which belongs to the Gypsy Oil Company.

The gases are not corrected to an air-free basis in calculated heat value, as the contamination with air is so smal.

TABLE No. 12.—Analyses of gases from Eldorado field, Butler county.

NAME OF LEASE.	Location.	Depth.	Volume when drilled in.
Stokes, No. 3	33–25– 5	880– 900	12,000 M. cu ft.
Gussman, No. 1	17,26– 5	885– 892	2,600 M. cu. ft.
Boyer, No. 4	17–26–15	887– 899	5,000 M. cu. ft.
Barnhill, No. 2	6–26– 5	1–130–1–145	1,500 M. cu. ft.
Howe, No. 23	5–26– 5	1,274 T. S.	1,200 M. cu. ft.
Boyer, No. 1	17–27– 5	1,170 T. S.	....
Robinson, No. 23	31–25– 5	1,505–1,510	....
J. A. Shumway, No. 1	11–26– 5	1,445 T. S.	....
H. Adsit, No. 3	35–25– 4	1,482–1,493	....

The Ellsworth County Field.

This is a field located in and around the city of Ellsworth, in Ellsworth county. Commercially it is of little importance, and no drilling is being done in this immediate field, though a considerable amount of "wild-catting" is in progress over the area between Ellsworth and Augusta.

The enormous salt bed of central Kansas underlies the city, and a local company put up an evaporating plant there some years ago. This plant operated successfully until the large vacuum plants of the state brought the price of salt production so low that it could compete no longer, since the high price of fuel in that locality was the greatest obstacle. In 1912 Mr. F. A. Merriweather and others formed a company to prospect for gas, with the hope of finding a supply sufficient for the salt plant. They put down seven wells ranging from 1,000 to 1,150 feet deep. Small flows of gas were found, but not enough to be of commercial importance. Gas was piped to private residences and used for some time, but at present only one of the wells is beng used.

The Work-Temple well, which was drilled on the city lot of Mr. Work, is at present supplying four houses. The other wells are idle and some of them are flooded.

The importance of this field lies in the fact that it is some distance from other known fields and that its chemical characteristics are somewhat similar to the Augusta and Eldorado gases. This might suggest a general distribution of gas between these two localities. The gas is of rather poor quality, as may be seen from Table No. 11. Since deeper wells in the Augusta field strike the gases which are lower in nitrogen and normal in heating values, it would be very interesting to know what deeper drillings in this area would show. The present knowledge might be correlated, and the data would prove very valuable, especially if an area similar to the Augusta field should be discovered. Inasmuch as the present gas is 1,000 feet deep, it would involve great expenditures to prospect for the lower formations.

The sands in this field are rather hard and fine grained, and the wells, although small, are quite long lived.

TABLE No. 13.—The analyses of gases from the Ellsworth county field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr.
							Higher.	Lower.	Air=1.
29-L	0.33	....	0.15	60.43	3.41	35.77	706	639	0.723
27-L	.26	....	.14	61.01	4.86	33.72	739	669	0.733
28-L	.36	....	....	62.42	2.34	34.88	709	640	0.713

TABLE No. 14.—Data regarding the wells in the Ellsworth county field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.	Well name.	Well No.	Depth, feet.	Depth to top of sands, feet.	Thickness of sands, feet.
27-L	Lot 25, Ellsworth	Work-Temple	......	1,106	980 1,080 1,100	5 5 5
28-L	Lot 3, Blake addition	M. A. Merritt	1	1,140	1,000 1,000	5 5
29-L	Lot 4, Butler addition	J. Warr	1	1,100	905 1,065 1,100	5 5 5

TABLE No. 15.—The analyses of gases from Franklin county.*

CO_2.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr. Air-1.
					Higher.	Lower.	
0.48	0.24	92.56	0.14	6.55	988	897	0.587
.72	.00	91.40	2.80	5.06	1,026	931	.595
.36	.24	91.71	1.75	5.89	1,009	916	.591
.24	.48	58.53	27.23	13.52	1.130	1,036	.747

*Data furnished by Empire Gas and Fuel Company, Bartlesville, Okla.

TABLE No. 16.—Data regarding the wells in the Franklin county field from which were secured the samples listed in the foregoing table.

Location.			Farm name.	Well No.	Depth, feet.	Sample No.	Date sampled.	Date received.	Date of analysis.
Sec.	Twp.	R.							
33	21	17	J. W. Hughes	......	713	17,888	6-5-17	6- 7-17	6-12-17
15	21	17	F. S. Crones	......	....	17,889	6-5-17	6- 7-17	6-12-17
12	20	17	Fred Detwiler	1	719	17,887	6-5-17	6- 7-17	6-12-17
5	21	17	Crom	2	726	17,891	6-6-17	6- 7-17	6-12-17

The Fredonia, Wilson County, Field.

As has been the case with several other gas towns of Kansas, Fredonia, by reason of its supply, has attracted many manufacturing concerns.

At present the local company, the Fredonia Gas Company, produces enough gas to supply the town and to operate several manufacturing plants. The most important establishment

there at present is the brick plant, which makes its brick from a shale obtained from a big hill south of town, and known as South Hill.

The field which furnishes gas to the city at present is north and west of town. Most of the wells are comparatively new and some development is in progress. The sands are somewhat irregular and stray sands are often found. The formations seem to be considerably folded, and prospecting along defined anticlines usually produces good results.

The present field contains no oil. The accompanying table shows the composition of the gases of this field.

TABLE No. 17.—The Analyses of gases from the Fredonia field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr.
							Higher.	Lower.	Air=1.
215–L	0.76	....	0.22	90.72	3.00	5.30	1,022.00	928.00	0.598
218–L	.24	.49	....	77.96	9.56	11.76	1,023.00	926.00	0.656
219–L	.39	.49	.97	80.74	5.77	11.64	982.00	912.00	0.644
219–L	.07	.02	.74	84.00	4.79	10.37	983.00	928.00	0.623
220–L	.24	....	.24	84.88	4.97	9.68	996.00	906.00	0.622
221–L	.67	.24	.31	91.40	2.41	4.96	1,025.00	924.00	0.596
222–L	1.92	....	....	91.91	1.25	4.92	1,002.00	909.00	0.599
223–L	.58	....	....	90.21	2.79	6.45	1,012.00	920.00	0.599
224–L	.15	.13	....	85.26	4.58	9.87	997.00	906.00	0.619
225–L	.80	....	....	89.98	3.09	6.12	1,015.00	923.00	0.602

TABLE No. 18.—Data regarding the wells in the Fredonia field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Depth to top of sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date.	Rock pressure, in lbs. per sq. in.
	Sec.	R.	Twp.							
215–L (*a*)	3	15	29	Clark	1	725 770	5 10	900	6–15–15	225
No analysis (*b*)	29	15	29	Ritchey	3	1,095	30	22,000	6– 6–10	375
218–L (*c*)	5	15	28	Timmons	1	280	15	500	6– 1–13	80
219–L (*d*)	34	15	28	Farwell	3	650 705	5 8	2,000	6–16–15	225
219–L	5	15	29	H. Kidd	1	275	21	1,100	5–26–15	80
220–L	5	15	29	Nelson	1	280 130	17½ 60	800	6–20–15	80
221–L	15	15	29	Burton	4	980	20	2,000	12–28–11	125
222–L (*e*)	10	15	29	Van Hyning	4	810	15	1,000	10– 6–13	275
223–L (*f*)	14	15	29	J. Crooks	5	200 1,038	60 47	5,000	12–30–15	375
224–L	5	15	29	Knepper	2	225	23	5,000	7–27–15	80
225–L	27	15	29	Stewart	3	1,088	32	1,300	10–31–15	100

(*a*) The 725-foot gas comes from a formation of coal and sand, but is not of commercial importance. The second or 770-foot gas comes from a lime formation, according to drill records. This well was drilled ten feet into this lime.

(*b*) As can be seen from the data, this well is comparatively old. It has decreased from an initial production of 22,000,000 cubic feet daily to 150,000, and a rock pressure of from 375 to 25 pounds per square inch.

(*c*) This well was sunk to a depth of 1,165 feet, but no more sands were found. Its open flow on April 10, 1915, was 485,000 cubic feet and the rock pressure 15 pounds.

(*d*) The 703-foot gas in this well comes from the same lime as that in number 215-L; the shallow sand from the same coal and sand formation. In this well the shallow sand produced enough gas to save.

(*e*) This well, on October 15, 1915, had an open flow of 60,000 cubic feet and a rock pressure of 50 pounds per square inch.

(*f*) This is one of the older wells in the field, but on October 10, 1915, it had an open flow of 212,000 and a rock pressure of 75 pounds.

The Humboldt, Allen County, Field.

The following analyses are of gases from a field about nine miles northwest of Humboldt. The wells are owned by the Humboldt Brick Company. This company, and the Humboldt Gas Company, produce gas from this field and pipe it to the town for local distribution and for industrial purposes.

TABLE No. 19.—The analyses of gases from the Humboldt field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr.
							Higher.	Lower.	Air=1.
195–L	1.23	....	....	96.23	0.13	2.40	1,027	932	0.576
196–L	.70	.25	....	91.85	4.92	2.28	1,082	972	.596
197–L	1.24	.12	....	95.94	.82	1.88	1,040	943	.579
198–L	1.43	....	....	94.38	.76	3.43	1,019	926	.586
199–L	.72	.49	.24	92.92	2.52	3.11	1,050	949	.592
200–L	.97	.38	.34	93.32	2.11	2.88	973	944	.591

The Montgomery County Field.[35]

Montgomery county was one of the first in the state to utilize its gas supply. In 1889 a moderate supply of gas was found at Cherryvale, and about a year later the Coffeyville field was opened. It was not until 1893 that Independence was supplied with gas, and then only one company was operating in the field. With the widespread development of oil, beginning in 1903, enormous findings of gas were made. The Bolton field, when brought in, was estimated to have enough gas to supply all towns within a radius of 150 miles for 50 years, but the first 10 years almost exhausted the supply.

The extent of gas area in this county may be noted when we consider that Cherryvale in the northeast corner has a considerable development. The Independence field runs from Dearing to the north side of the county. Caney, in the southwest corner, has been one of the big fields of the state, and the Coffeyville area covers the entire south central part of the county.

The oil and gas are found in the coal measures above the Cherokee shales throughout most of the county. It is found in the same horizon in Woodson county in the vicinity of Neodesha. The gas-producing formations are not so continuous

35. The historical part of this discussion was taken for the most part from University Geological Survey, IX, 181 (1908).

as one would expect considering that the supply is so evenly distributed over the country. Instead, gas and oil are found in lenticular formations, as proven by the dry holes that may be encountered between good wells. Furthermore, the gas may be found above, below or with the oil-producing formations. Some gas and oil are found at horizons varying from 500 to 600 feet, but most of the gas that is now being utilized comes from a sand that shows no oil and is from 800 to 1,000 feet deep.

The oil sand is encountered at a depth of from 600 to 800 feet in some of these wells, and in one, the McBride, some oil occurs with the gas.

It is characteristic of the wells, especially around Independence, that they come in at enormous flow, in some cases as much as 33,000,000 cubic feet per day. A number of them came in at 20,000,000 cubic feet. Since the field has become somewhat depleted, the initial flow is much less, but some of the old wells, after five to seven years, still flow from 2,000,000 to 6,000,000 cubic feet daily.

The apparently inexhaustible supply of gas in this field early induced many large manufacturing concerns to locate there. Brick plants, zinc smelters and glass factories came in, and for a short time enjoyed the benefits of very cheap fuel. In many cases these companies acted as their own producers and obtained large leases, upon which they kept drills running to supply the gas as needed. In the year 1904 the Kansas Natural began to pipe the gas away from Montgomery county to Joplin, Kansas City and other Missouri and Kansas towns. This, in addition to the extensive use by local manufacturers, soon began to tell on the supply. By efforts at conservation, and by constantly keeping the drill going the large consumers are yet able to use gas, and the pipe-line companies are yet piping the supply away; however, there is no doubt but that the future supply of gas for this particular territory will depend upon the newer fields alone.

TABLE No. 20.—The analyses of gases from the Montgomery county field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr.
							Higher.	Lower.	Air=1.
116–L	0.44	0.24	0.24	95.45	1.66	1.95	1,038	955	0.578
132–L	1.21	.12	....	92.68	2.52	3.46	1,036	941	.592
133–L	1.03	.37	....	79.67	15.18	3.74	1.142	1,049	.627
135–L	.91	.34	.24	92.68	2.20	3.66	1,038	939	.612
137–L	....	....	.39	90.99	5.59	3.03	1,082	975	.595
139–L	.72	.38	....	83.92	11.49	3.49	1,115	1,005	.634
140–L	.75	....	.49	89.11	5.23	4.42	1,046	951	.607
141–L	1.53	.24	.51	91.59	3.13	2.98	1,046	948	.605
142–L	.25	.44	.29	86.72	3.91	8.37	1,007	909	.618
145–L	1.05	.24	.12	89.77	4.91	3.91	1,060	955	.607
147–L	.12	.24	....	75.87	19.87	3.88	1,119	1,075	.642
152–L	.90	.47	.22	85.91	9.12	3.38	1,099	995	.624
154–L	.49	.40	.27	85.69	9.35	3.78	1,008	996	.622
155–L	.49	.37	....	79.51	15.27	4.36	1.142	1,043	.648
156–L	.72	.37	.17	91.24	4.81	2.67	1,072	970	.608
5	.24	.24	.25	83.04	8.54	7.79	1,093	970	....
1	....	.42	.18	72.13	13.80	13.46	1.117	957	....

TABLE No. 21.—Data regarding the wells in the Montgomery county field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Open flow, in 1,000 cu. ft.	Date.	Rock pressure, in lbs. per sq. in.	Total depth, feet.	Depth to top of sand, feet.	Thickness of sand, feet.
	Sec.	R.	Twp.								
116–L	35	16	34	....	...	....	....	100	815	800	15
132–L	27	15	31	S. H. Hinson	1	1,400	7–1–04	400	850	....	.....
133–L	3	15	32	J. M. McBride	2	500	....	....	1,020	972 1,005	15 14
134–L	25	15	33	John Klump	4	15,322	11–23–09	180	1,107	776 1,072	12 35
137–L	24	15	33	J. B. Compton	5	21,153	12–17–09	160	1,094	1,054	40
139–L	.....	.....	.....	Barr	6	....	....	....	....	....	.....
140–L	10	15	32	D. J. Ringle	7	784	9–13–13	140	1,008	990	18
141–L	18	16	34	Mary Ostergard	1	1,096	6–30–15	....	1,114	1,051	63
142–L	26	15	33	J. E. Johnson	1	17,000	....	355	1,112	....	.....
145–L	14	15	32	Armstrong	3	....	1914	....	....	....	.....
147–L	11	15	32	Etter	2	....	....	....	....	....	.....
152–L	14	15	32	Long	1–2	....	1913	....	....	....	.....
155–L	7	16	32	Uitts	1	....	1914	....	....	....	.....
156–L	14	15	32	Coleman	3	....	1914	....	....	....	.....
5	.....	17	33	Boozell	...	5,000	....	180	500	....	60
1	3	13	34	Whistler	...	3,000	....	145	....	325	100

The Neodesha, Wilson County, Field.

The present gas-producing area may be said to extend from Altoona to the Montgomery county line. Several samples were procured north of Neodesha about four miles, some just outside the town and some south as far as Montgomery county.

TABLE No. 22.—The analyses of gases from the Neodesha field.

LAB. No.	Name.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr. Air=1.
								Higher.	Lower.	
208–L	Tommey No. 1	0.48	0.48	......	85.78	9.29	3.96	1,099	993	0.624
209–L	Betty Duncan, No. 11	.56	.41	.24	91.36	1.98	5.43	1,021	923	.597
210–L	C. & L. Bray	.75	......	......	78.84	11.25	9.15	1,049	956	.653
211–L	Schydder, No. 2	.73	.24	.24	84.86	6.88	7.02	1,037	943	.617

The Ottawa, Franklin County, Field.

A new field has been opened south and east of Ottawa, in Franklin county, Kansas. The nearest field to this is the Rantoul field in the eastern part of the same county. Rantoul has been an oil-producing region for some time, but no samples of gas were obtained from this area. The Ottawa field is at present producing gas only. The following table contains analyses of gases made from this field.

TABLE No. 23.—The analyses of gases from the new Ottawa field.

Lab. No.	Location.			Name.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.	
	Sec.	R.	Twp.								Higher.	Lower.
148-L	11	20	17	Thompson..	18	......	*.....	87.00	6.67	5.47	1,038	946
149-L	14	20	17	Miller......	49	......	*.....	90.02	3.30	4.45	1,021	928
150-L	33	21	16	Osborn.....	64	.27	*.....	79.52	15.32	4.23	1,139	1,036

*All three samples were calculated air free, but contained oxygen as follows: 148-L, .51 per cent; 149-L, 1.50 per cent; 150-L, 1.29 per cent.

The Winfield, Cowley County, Field.

Developments were started in this field in the spring of 1915 by the Cowley County Gas Company. Later the Grace Oil Company began to prospect here, and shortly afterward the Wichita Natural Gas Company also entered the field.

The field is located about six miles southeast of town, in the Walnut river valley. There were in 1917 fifteen wells, all of which were situated in ranges 4 and 5, township 33. These wells ran from 250,000 to 2,000,000 feet and came in at a rock pressure of about 280 pounds.

It is noteworthy that while prospecting was begun in the spring of 1915, by the close of that year three companies had lines going into the city which were supplying gas to industrial plants. These lines carried a pressure of about 150 to 160 pounds.

All of the prospecting which has been done here indicates that the sands are very irregular and probably lenticular. In one well a good sand will be found at a given horizon, and in an adjoining location a sand will appear at an entirely different depth, or perhaps will not be found at all. Thus far no oil has been located in the field. The gas is found at depths ranging from 300 to 1,200 feet.

The following tables give the characteristics of this field and the chemical composition. In considering the variations mentioned, it is to be noted that in the wells from which samples Nos. 38-L and 41-L were taken there is found what is locally termed "regular sand." Sample No. 39-L was found in two sands; No. 40-L is from the second sand, the first or regular one being absent, and No. 42-L is from a lower sand. This undoubtedly accounts for the variation in composition.

TABLE No. 24.—The analyses of gasses from the Winfield field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u.		Calculated sp. gr.
							Higher.	Lower.	air=1.
38-L	....	0.24	....	76.79	10.69	12.27	1,024	926	0.660
39-L	0.25	....	0.24	75.74	12.69	11.07	1,043	946	.575
40-L	.36	....	.24	77.90	9.51	11.98	1,007	912	.654
41-L	....	.37	.12	76.24	10.52	12.72	1,019	920	.661
42-L	.18	.37	.19	77.15	6.99	15.10	962	873	.656
191-L	.00	.12	.16	97.16	8.34	12.19	1,089	911	....
192-L	.12	.36	.61	71.77	10.75	16.38	1,079	894	....
88	.13	.00	.37	16.27	3.10	80.23	....	209	....

TABLE No. 25.—Data regarding the wells in the Winfield field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Open flow.	Rock pressure, in lbs. per sq. in.	Date of test.	Depth to top of sand, feet.	Thickness of sand, feet.
	Sec.	R.	Twp.							
38-L	14	4	33	C. O. McCollum,	2	500,000	280	7-1-15	{568 {535	8 2
39-L	14	4	33	T. D. McCollum,	1	1,600,000	280	....	575	12
40-L	12	4	33	L. F. Johnson...	1	75,000	280	4-10-15	621	10
41-L	12	4	33	C. H. Marshall..	1	1,250,000	280	4-30-15	{577 {619	12 ....
42-L	12	4	33	W. H. Melville..	1	100,000	280	5-14-15	589	12
191-L	......	......	......	W. E. Silliman..	2	....	....	....	....	....
192-L	1	4	32	E. R. Graham...	1	....	....	....	....	....
88	24	6	33	Preston........	1	8,500,000	400	....	1,010	....

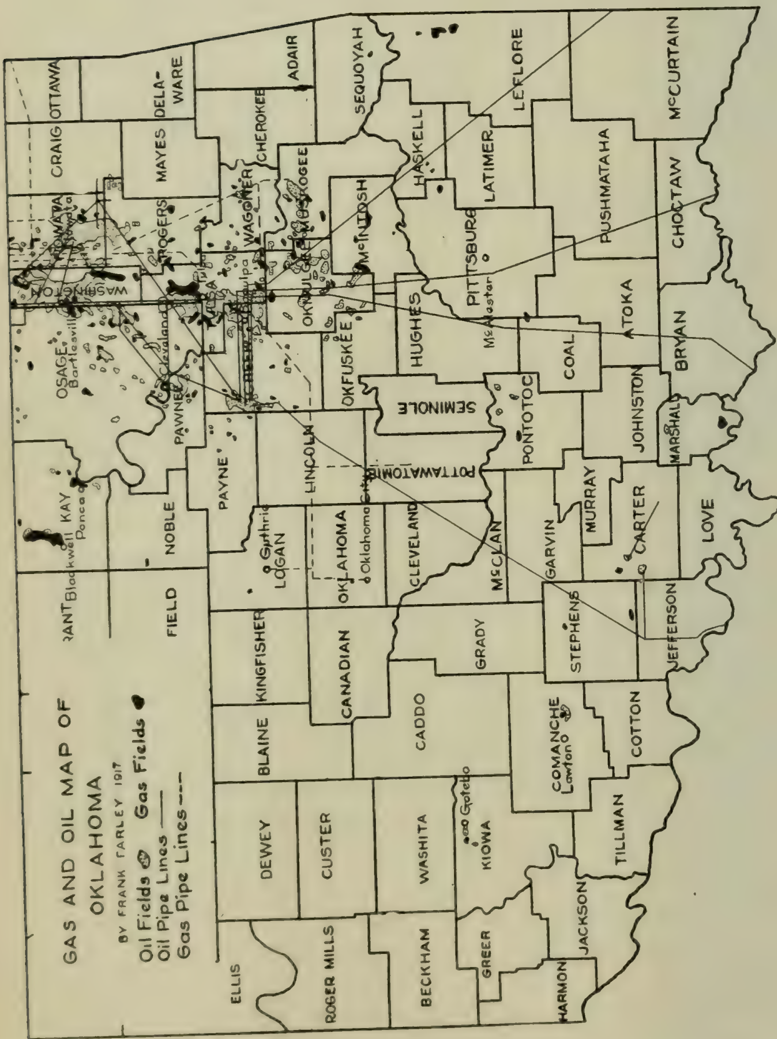

GAS AND OIL MAP OF
OKLAHOMA
BY FRANK FARLEY 1917
Oil Fields
Gas Fields
Oil Pipe Lines
Gas Pipe Lines
OTTAWA
CRAIG
DELA-WARE
MAYES
ADAIR
CHEROKEE
SEQUOYAH
NOWATA
ROGERS
WAGONER
MUSKOGEE
HASKELL
LEFLORE
WASHINGTON
OSAGE
Bartlesville
KAY
Ponca
Blackwell
GRANT
NOBLE
PAWNEE
PAYNE
CREEK
OKMULGEE
McINTOSH
LATIMER
PITTSBURG
McAlester
PUSHMATAHA
McCURTAIN
CHOCTAW
ATOKA
COAL
HUGHES
OKFUSKEE
SEMINOLE
PONTOTOC
JOHNSTON
BRYAN
MARSHALL
LINCOLN
POTTAWATOMIE
LOGAN
Guthrie
OKLAHOMA
Oklahoma City
CLEVELAND
McCLAIN
GARVIN
MURRAY
CARTER
LOVE
FIELD
KINGFISHER
CANADIAN
GRADY
STEPHENS
JEFFERSON
BLAINE
CADDO
COMANCHE
Lawton
COTTON
DEWEY
CUSTER
WASHITA
KIOWA
Gotebo
TILLMAN
ELLIS
ROGER MILLS
BECKHAM
GREER
JACKSON
HARMON

FIG. 3.

Part III.

OKLAHOMA GAS FIELDS, AND ANALYSES OF TYPICAL GASES.

The Blackwell, Kay County, Field.

DRILLING was begun for oil and gas on the town site of Blackwell, Okla., in 1904 by local capitalists. Red beds caused trouble by caving in, and the first two or three wells were abandoned. Since sufficient indications were present to justify further operations, drillings were continued north, with the result that the present Blackwell field was opened. This field, as developed, is about one mile wide and extends through the eastern part of townships 27, 28 and 29, in range 1 west. The wells, for the most part, are in the same sands. The producing sand, on an average, is about 750 feet deep; other nonpaying sands are found from 125 to 985 feet. According to the United States Geological Survey,[36] the sand is geologically the highest producing in the state, and is believed to be the same sand that is productive at Ponca at 250 feet. The sands which produce at Cleveland, if persistent, should be found 200 to 300 feet deeper than at Ponca; that is, they should be about 2,800 to 3,000 feet. The Bartlesville sand should be about 3,600 to 3,800 feet, the Tucker 3,900 to 4,100 feet. Drillings are now being made to these sands. The same trouble is being experienced with the red beds caving in, and in order to eliminate this trouble the rotary drill is being used.

Developments to the north of this field reveal the presence of deeper and more productive sands found at the 730-foot level. Probably when the present wells are exhausted they will be drilled to deeper sands.

In the present field no oil has been found. In fact, oil was discovered in only one well in the shallow sand throughout the whole Blackwell area. This well was an old one, on the present town site, but deep drillings in this region are revealing great oil possibilities.[37]

As was mentioned, all of the wells in this area are in the same sand except the Sharp No. 4, which is in a sand about 900

36. Wood, U. S. Geological Survey, Bulletin 531-B, 29.

37. Since this was written much development has taken place in this locality.

feet deep. The analysis of gas from this well does not differ materially from that of gas found in the usual sand.

It is of interest to note that the two wells farthest north in the pool have a heating value different from the ones in the lower end of the field. This might be accounted for by assuming that the south end of the pool was in contact with oil and that diffusion was not rapid enough for the heavier constituents to reach the extreme north end as fast as they were taken off.

Absorption and filtration processes may also play an important part in the variation in composition of these and other gases.

TABLE No. 26.—The analyses of gases from the Blackwell field.

Lab. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u.		Calculated sp. gr
							Higher.	Lower.	air=1.
55–L	0.24	0.49	0.17	76.59	14.83	7.68	1,105	1,004	0.666
56–L	....	.38	....	78.77	15.48	5.36	1,137	1,028	.655
57–L	.12	.44	.32	76.26	17.74	5.11	1,154	1,043	.668
58–L	.24	.24	.24	78.72	15.54	4.99	1,134	1,032	.655
60–L	.32	.65	.25	70.44	17.87	10.45	1,053	997	.694
61–L	....	.24	.24	74.14	18.70	6.65	1,144	1,043	.675
62–L	....	.44	.69	75.74	16.92	6.18	1,138	1,031	.669

TABLE No. 27.—Showing the lower heating value of the wells indicated at an earlier date than the above.

Lab. No.	Location.			Farm name.	Well	Date.	B. t. u.
	Sec.	R.	Twp.				
101	24	1	28	Larrabee	1	2-2-14	1,043
102	24	1	28	Larrabee	2	2-2-14	1,044
103	12	1	28	Archer	5	2-2-14	1,031
104	13	1	28	School Section	10	2-2-14	1,025
105	13	1	28	School Section	12	2-2-14	1,023
107	25	1	28	School Section	4	2-4-14	1,033

TABLE No. 28.—Data regarding the wells in the Blackwell field from which were secured the samples listed in the foregoing table.

Lab. No.	Location.			Farm name.	Well No.	Initial opening, in 1,000 cu. ft.	Rock pressure, in lbs. per sq. in.	Date completed.	Last open flow, in 1,000 cu. ft.	Test rock pressure, in lbs. per sq. in.	Date.
	Sec.	R.	Twp.								
55–L	12	1W	28N	Archer	1	1,000	300	2- 2-13	856	205	7-14
56–L	13	1W	28N	School Section,	1	1,250	300	7-12-12	430	200	7-14
57–L	36	1W	28N	School Section,	2	750	325	11-11-12	430	215	7-14
58–L	13	1W	28N	School Section,	9	7,000	325	10-16-12	350	175	7-14
59–L	36	1W	28N	School Section,	1	1,600	325	10-25-12	875	215	7-14
60–L	36	1W	29N	School Section,	1	554	335	8-18-13	690	315	7-14
61–L	25	1W	28N	H. M. Sharp	4	8,500	200	1-22-13	1,985	155	7-14
62–L	25	1W	28N	H. M. Sharp	1	431	430	4-17-13	500	430	7-14

RECORD OF WELL No. 1.
(Sec. 13–28 N–1W).

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	9	9	Lime	10	476
Slate	30	39	Red rock	15	491
Lime	17	56	Slate	25	416
Slate	10	66	Lime	15	531
Lime	15	81	Red rock	2	533
Slate	39	120	Lime	5	538
Lime	10	130	Slate	40	578
Slate	50	180	Lime	25	603
Lime	20	200	Slate	5	608
Slate	25	225	Red rock	15	623
Broken lime	20	245	Lime	10	633
Slate	30	275	Slate	15	648
Lime	15	290	Broken lime	12	660
Red rock	35	325	Red rock	10	670
Slate	20	345	Slate	25	695
Lime	5	350	Lime	10	705
Slate	10	360	Slate	40	745
Lime	15	375	Red rock	10	755
Slate	20	395	Slate	4	759
Lime	25	420	Lime	5	764
Red rock	20	440	Gas sand	7	771
Slate	10	450			
Sand	16	466	Total depth	....	771

RECORD OF ARCHER WELL No. 1.

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	4	4	Lime	15	514
Broken lime	10	14	Slate	5	519
Red rock	15	29	Lime	5	524
White shale	31	60	Sand	5	529
Lime	10	70	Red rock	16	545
Slate	19	89	Lime	5	550
Lime	12	101	Sand (water)	15	565
Slate	12	113	Lime	5	570
Lime	5	118	Slate	8	578
Slate	10	128	Red rock	16	594
Lime	8	136	Lime	15	609
Slate	15	151	Slate	5	614
Lime	20	171	Lime	5	619
Slate	34	205	Red rock	10	629
Lime	4	209	Lime	12	641
Slate	26	235	Slate	3	644
Lime	65	300	Lime	6	650
Slate	10	310	Slate	5	655
Lime	5	315	Red rock	20	675
Sand	12	327	Slate	10	685
Red rock	35	362	Lime	15	700
Slate	10	372	Slate	35	735
Shale	10	382	Red rock	35	770
Slate	11	393	Sand	12	782
Lime	8	401	Slate	24	806
Slate	49	450	Lime (cap rock)	6	812
Water sand	21	471	Gas sand (gas at 818 feet)	10	822
Red rock	28	499			
			Total depth	....	822

RECORD OF SHARP WELL No. 1.

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole. feet.
Soil	5	5	Lime	25	385
Clay	25	30	Sand	15	400
Lime	1	31	Red rock	30	430
Shale	21	52	Slate	10	440
Lime	6	58	Sand	25	465
Slate	9	67	Red rock	5	470
Lime	28	95	Lime	30	500
Slate	15	110	Sand	15	515
Lime	20	130	Slate	10	525
Sand	15	145	Red rock	15	540
Lime	8	153	Lime	22	562
Shale	20	173	Red rock	15	577
Lime	10	183	Lime	8	585
Slate	27	210	Red rock	5	590
Lime	20	230	Lime	5	595
Slate	5	235	Red rock	20	615
Lime	15	250	Lime	3	618
Red rock	25	275	Slate	25	643
Slate	15	290	Red rock	27	670
Sand	10	300	Sand	30	700
Slate	5	305	Slate	3	703
Sand	10	315	Sand	20	723
Slate	20	335	Red rock	17	740
Lime	5	340	Lime (cap rock)	10	750
Slate	20	360	Sand (gas)	5	755
			Total depth		755

RECORD OF SHARP WELL No. 4.

Strata.	Thickness of strata, feet.	Depth of hole, feet.	Strata.	Thickness of strata, feet.	Depth of hole, feet.
Soil	3	3	Slate	20	665
Clay	10	13	Sand	5	670
Slate	32	45	Red rock	35	705
Lime	4	49	Sand	16	721
Slate	16	65	Red rock	21	742
Lime	10	75	Cap rock	14	756
Brake	2	77	Gas sand	12	768
Lime	10	87	Slate	16	784
Slate	10	97	Lime	2	786
Lime	18	115	Slate	7	793
Slate	12	127	Lime	5	798
Lime	12	139	Slate	8	806
Shale	5	144	Lime	17	823
Sand	10	154	Slate	17	840
Slate	8	162	Lime	60	900
Sand	11	173	Slate	15	915
Lime	22	195	Lime	15	930
Slate	15	210	Slate	58	988
Lime	10	220	Gas sand	3	991
Slate	40	260	Slate	20	1,011
Red rock	30	290	Dry sand	15	1,026
Slate	45	335	Shale	14	1,040
Lime	20	355	Lime	2	1,042
Shale	15	370	Slate	100	1,142
Sand	50	420	Lime	2	1,144
Red rock	30	450	Slate	26	1,170
Lime	10	460	Lime	2	1,172
Slate	5	465	Slate	53	1,225
Lime	5	470	Lime	25	1,250
Shale	5	475	Water sand	50	1,300
Red rock	5	480	Slate	5	1,305
Sand	40	520	Lime	25	1,330
Red rock	20	540	Slate	5	1,335
Lime	25	565	Lime	10	1,345
Red rock	10	575	Slate	55	1,400
Lime	11	586	Lime	30	1,430
Red rock	4	590	Shale	35	1,465
Lime	10	600	Lime	5	1,470
Red rock	25	625	Slate	8	1,478
Broken lime	5	630	Sand (water)	15	1,493
Broken sand	15	645			
			Total depth		1,493

The Craig County Field.

In 1914 gas was found in the northern part of Craig county, Oklahoma. Five wells were drilled in the field, gas being found in a coal formation. These wells were small, having an open flow of from 1,000,000 to 2,500,000 cubic feet daily, with an initial rock pressure of 150 pounds. The gas-producing coal formation is from 430 to 540 feet deep. In 1915 the Quapaw Gas Company drilled another well on section 21, range 9, township 18, which struck about 1,000,000 feet of gas at 540 feet. The well was drilled 200 feet into the Mississippi limestone without a further showing of oil or gas.

This area is located far enough to the east so that only the Lower Pennsylvanian is present and the Mississippi limestone is reached at about 600 feet.

There were at the time this was written only three producing wells in the field, for the remainder filled with water as soon as they began to be utilized. No gas lines have been piped into the field, and the wells are being used only for developing purposes. Thus far no oil has been found.

The following table shows the character of the gas from the field. No. 88-L is so highly contaminated that the analysis is hardly reliable. The gases are rather high methane gases with low residues and low ethane.

TABLE No. 29.—The analyses of gases from Craig county, Oklahoma.

Lab. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u.
88-L	1.56	0.07	6.09	64.49	2.89	24.88	968
1	.65	.39	.93	92.04	.86	5.13	965
244-L	.52	.52	.00	93.53	3.15	2.28	958
255-L	.50	.00	.00	90.70	5.59	3.22	959

TABLE No. 30.—Data regarding the wells in the Craig county field from which were secured the samples listed in the foregoing table.

Lab. No.	Location.			Farm name.	Well No.	Depth to sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date well completed.	Rock pressure in lbs. per sq. in.
	Sec.	R.	Twp.							
88-L	1	17	27	Tritthart	1	730	20	2,500	7-14	300
1	15	18	29	Drake	2	*405	....	1,300	1914	150
244-L	21	18	29	Hedrick	2	440	8	1,475	3-15	150
255-L	21	18	29	Hedrick	3	438	5	2,500	12-23-15	150

* Total depth.

The Cushing, Payne County, Field.

With the widespread development for oil around Cushing, some very promising gas fields were opened, and one of the pipe-line companies began to lay in a large line to take care of the gas. The excitement over oil was so great that the gas was allowed to "blow," and the result was that before the company could get its line in the field the supply was exhausted. Other fields were soon opened, however, and the pipe line was used to transport the gas.

Table No. 31 gives the analyses of the gases from the Cushing field.

TABLE No. 31.—Analyses of gases from the Cushing field.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.
4	Trace	0.12	Trace	70.74	21.64	7.49	1,059
5	Trace	.48	.08	67.40	19.81	12.06	1,001
6	.83	.42	.42	67.26	18.96	12.14	984
9	.13	.54	.54	63.20	24.20	11.00	1,039
10	.12	1.00	.50	64.49	27.34	6.56	1,112
12	Trace	.87	.55	64.50	20.30	13.70	988

TABLE No. 32.—Data regarding the wells in the Cushing field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Sand.	Date sample was submitted.
	Sec.	R.	Twp.				
4	28	7	18		1		1–28–14
5	20	7	18		1	Layton	1–19–14
6	6	7	18	Mars	1		1–20–14
9	33	7	18	Magnolia Mickey	1	Wheeler	1–19–14
10	28	7	18		1	Layton	1–19–14
12	20	7	18	Isaac Wocache	1	Wheeler	1–19–14

The Osage County Field.

Various oil and gas fields of importance have been developed in this county, among which are Hominy creek, Pawhuska, Bigheart, and the so-called North Osage field. Very few data are at hand on the Pawhuska, Bigheart and Hominy creek fields, excepting several analyses of various gases, which will be found in the tables.

The North Osage field, located in townships 28 and 29, range 10, was discovered in 1913 in the course of drilling for oil. As a rule, the gas sand is below the oil sand, but occasionally the gas and oil are found together. The wells are about 1,600 feet

deep. The gas started with an initial pressure of 700 pounds per square inch, but has now dropped considerably below this figure. Each well produces an average of 1,000,000 cubic feet daily.

The Indian Territory Oil and Illuminating Company hold all of the leases and are the sole producers. The entire supply is bought by the Wichita Natural Gas Company and piped to towns in Oklahoma and Kansas. The lines leading from the field have a pressure of 300 pounds per square inch.

The gas is of very good quality, usually runnng over 950 B. t. u. per cubic foot, and often going as high as 1,000.

TABLE No. 33.—The analyses of gases from Osage county, Oklahoma.

NORTH OSAGE FIELD.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr. Air=1.
							Higher.	Lower.	
172-L	0.00	0.12	0.64	89.28	5.67	4.29	1,059	*1,002	0.604
173L	1.21	.82	.19	83.82	5.12	8.82	1,010	908	.636
141-L	.82	.95	.96	69.79	14.51	12.99	1,038	*987	.700
42	.66	.40	.13	72.28	14.75	11.80	1,055	960	.686
45	1.20	.40	.54	69.65	14.92	13.28	1,030	937	.700
49	.28	.41	.70	71.50	16.16	10.96	1,073	976	.688
51	.40	.80	.54	72.64	13.62	12.00	1,048	950	.693
53	.84	.38	1.25	66.57	16.27	14.79	1,022	*981	.713
56	1.52	....	.28	74.64	13.26	10.32	1,042	950	.588
58	1.56	....	.29	73.92	12.12	12.12	1,013	924	.680
PAWHUSKA.									
3	0.94	Trace	1.38	88.00	4.80	4.88	1,027	933	.614
11	.43	.21	.53	69.10	18.80	10.93	1,091	992	.699
14	.77	.15	.62	90.90	5.40	2.16	1,073	971	.601
HOMINY CREEK.									
13	0.16	0.46	1.07	79.09	11.47	7.76	1,068	970	.654
15	.67	.28	.53	77.44	11.76	9.05	1,051	957	.659
23	Trace	.00	Trace	75.65	8.69	15.66	967	881	.661
24	.24	.00	.48	79.39	5.58	14.31	949	863	.645
162-L	.32	.40	.24	52.82	26.66	19.56	1,069	977	.772
OTHER OSAGE COUNTY WELLS.									
171-L	3.26	0.18	0.13	90.22	3.25	2.98	1,026	959	0.616
175-L	4.17	.00	.24	93.69	.00	1.90	998	905	.603
170-L	.00	.00	.27	82.20	3.02	14.51	932	846	.630
BIGHEART.									
7	0.86	0.15	0.30	78.90	16.43	3.34	1,150	1,048	0.659
8	1.21	1.07	.27	70.46	20.63	6.36	1,162	1,054	.704
16	1.26	.70	.42	82.75	12.00	2.87	1,123	1,018	.645

*Air free.

TABLE No. 34.—Data regarding the wells in the Osage county field from which were secured the samples listed in the foregoing table.

NORTH OSAGE FIELD.

Lab. No.	Location. Sec.	Location. R.	Location. Twp.	Farm name.	Well No.	Depth to sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date drill in.	Rock pressure, in lbs. per sq. in.	Latest test. Open flow, in 1,000 cu. ft.	Latest test. Date.	Latest test. Rock pressure, in lbs. per sq. in.
172-L	27	10	27	Osage County	3	1,670	15	10,000	11–14	600	2,000	6–15	530
173-L	27	10	27	Osage County	4	1,978	16	6,000	8–14	765	4,000	6–15	620
No sample	27	10	35	Osage County	2	1,420 1,606	3 21	5,800	1–13	550	1,350	12–14	370
No sample	26	10	2	Osage County	2	1,791 1,898	9 20	2,500	2–09	715	1,100	12–14	490
41	20	10	28		1	*							
42	2	10	28	Osage County	1	†							
45	34	10	29	Belmont Oil Co	12	*							
49	2	10	28	Foster & Leach	4	*							
51	2	10	28		5								
53	26	10	29	Foster	1								
56	33	10	29	Steyner Oil Co	2								
58	27	10	29	Stevner Oil Co	1								

*Deep sand. †Middle sand.

PAWHUSKA.

Lab. No.	Sec.	R.	Twp.	Farm name.	Well No.	Depth to sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date drill in.	Rock pressure	Open flow	Date	Rock pressure
3	2	9	25	Ind. Ter. Oil & Ill. Co	3								
11	3	9	25	P. O. & G	11								
14	3	9	25	P. O. & G	14								

HOMINY CREEK.

Lab. No.	Sec.	R.	Twp.	Farm name.	Well No.	Depth to sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date drill in.	Rock pressure	Open flow	Date	Rock pressure
13	11	10	22	Steel	1								
15	11	10	22	Steel	1								
23	9	8	23	White & Sinclair	3								
24	8	8	23	White & Sinclair	4								
162-L	27	8	22	White	1			2,200	8-12-15	298			

OTHER OSAGE COUNTY WELLS.

Lab. No.	Lot.	R.	Twp.	Farm name.	Well No.	Depth to sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date drill in.	Rock pressure	Open flow	Date	Rock pressure
171-L	260	11	27	Osage County	1	1,740* 1,897	12 30	2,500	10–13	750			
175-L	194	11	26	Osage County	2	1,486† 1,594	15 27	2,800	2–10	550			

*Showing of oil at 1,740 feet. †Bartlesville sand at 1,486 feet, but no oil or gas.

BIGHEART.

Lab. No.	Lot	R.	Twp.	Farm name.	Well No.	Depth to sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date drill in.	Rock pressure	Open flow	Date	Rock pressure
7	298				20								
8	298				19								
16	298				17								

WELL No. 16, OSAGE COUNTY.
(Sec. 34–29–10.)

Sand.	Top, feet.	Bottom, feet.	Sand.	Top, feet.	Bottom, feet.
Top of gas	520	525	2½ million feet of gas	1,015	1,025
Water	525	700	Shale	1,025	1,035
Shale	700	840	Lime	1,035	1,041
Shale	840	890	Sand	1,041	1,060
Lime	890	910			
Shale	910	1,015	Total depth		1,060

Initial production, 200 bbls; production 100 bbls. two weeks after drilled in.

WELL No. 2. PAWHUSKA FIELD.
(Sec. 2–25–9.)

Sand.	Top, feet.	Bottom, feet.	Sand.	Top, feet.	Bottom, feet.
1 inch water		175	Break	1,661	1,665
Hole wet to		609	Lime	1,669	1,669
2 inches water		1,050	1 inch gas		1,698
Big lime	1,400	1,415	2 inches gas		1,706
Break	1,415	1,430	More gas		1,718
Lime	1,430	1,480	Big gas		1,725
Oswego lime, slate and shell	1,605	1,661			

The Ponca City, Kay County, Field.

In 1905 and 1906 a local company began prospecting for oil in the southern part of the town site of Ponca City, Kay county, and found gas at a depth of from 500 to 550 feet. The development extended north two or three miles to section 22, and several wells ranging in production from 100,000 to 1,000,000 cu. ft. were found. This field soon ran low, and in 1909 a company prospecting farther north and east located the present field, which supplies gas to Ponca City and Killdeer.

This field, though not remarkable in any way, has produced several million feet of gas daily. It is located in ranges 2 and 3 east, townships 26 and 27. The wells range from 400 to 550 feet deep and have a volume of from 500,000 to 2,000,000 cubic feet per day. They decline quite rapidly because the city is supplied by only a few wells.

Geologically, the sands encountered at 500 feet in this region are among the highest in the state. The horizon at which the wells begin is nearly that of the Wreford limestone, which is, according to Prosser, the base of the Permian. In this vicinity this limestone is found less than 100 feet deep.

South of Ponca City, the 101 Oil Company has found several good wells by drilling to depths from 500 to 900 feet. On sec-

tion 8, township 25, range 2 east, the 101 Oil Company drilled a well which struck a five-foot sand at 125 feet, and another ten-foot sand at 265 feet. A well, which produced 5,000,000 cubic feet daily, was found at 503 feet, an 8,000,000 cubic foot flow was encountered at 900 feet, and a 20,000,000 cubic foot supply was found in a sand at 1,315 feet where drilling ceased. Oil is found in this field south of Ponca, but the above mentioned sands are gas-producing only.

The variation in composition of the gases from these wells is quite marked, the sample from the Marguerette Primaux well being the lowest in heating value. This gas comes from a sand about 500 feet deep in a well which is 3,765 feet deep. No other gas was found in this well. It was mentioned that these sands were perhaps in the same horizon as the producing sands in the Blackwell field and it looks as though this gas might be the same as some of the shallow gases found near Blackwell, but there are not data sufficient to justify correlation. Number 52-L, Table 38, is a casing-head gas, and therefore, has a high heating value.

TABLE No. 35.—The analyses of gases from the Ponca City field.

LAB. No.	CO_2.	O_2.	HHC.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u.		Calculated sp. gr. Air=1.
							Higher.	Lower.	
44-L	0.12	....	0.12	78.78	13.93	7.03	1,101	1,004	0.653
45-L	1.00	....	.23	84.16	7.53	7.08	1,043	947	.632
46-L	.05	.40	....	44.60	14.86	40.10	752	687	.795
47-L	.71	.63	.07	84.94	5.42	8.23	1,007	914	.625
48-L	.50	.50	....	77.68	10.25	11.07	1,018	927	.657
49-L	.20	.20	.33	77.48	11.26	10.52	1,044	948	.658
51-L	.28	.41	.13	72.60	16.80	9.79	1,089	991	.682
52-L	.82	.65	3.02	22.95	63.40	9.14	1,506	1,376	.939

TABLE No. 36.—Data regarding the wells in the Ponca City field from which were secured the samples listed in the foregoing table.

LAB. No.	Location.			Farm name.	Well No.	Depth to top of sand, feet.	Total depth, feet.	Open flow, in 1,000 cu. ft.	Date completed.	Rock pressure, in lbs. per sq.in.
	Sec.	R.	Twp.							
44-L	12	2	26	Smedley	1	498	508	500	1909	175
45-L	9	3	27	Smith	3	....	465	....	1904	145
46-L	2	2	25	Primaux	7	*500	3,765	5,000	1913	200
47-L	9	3	27	Simmons	1	....	....	....	1914	140
48-L	8	3	27	Doughty	1	*390	400	3,000	1914	155
49-L	11	2	26	Muchow	1	545	555	500	1914	80
51-L	24	2	26	Kennedy	1	455	460	1,750	1909	165
52-L	8	2	25	Burt	...	*560	....	10,000	1912	200

*Approximate depth.

Analyses of Gases from Other Fields.

TABLE No. 37.—The analyses of gases from the Bartlesville, Washington county; Hogshooter, Washington county, and Wann, Nowata county, fields.

BARTLESVILLE.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u. Higher.	Heat value, 0° C., 760 mm., B.t.u. Lower.	Calculated sp. gr. Air=1.
237	1.07	0.22	0.38	85.53	5.75	7.05	1,024	927	0.624
217	1.51	.39	.44	81.16	8.20	8.40	1,032	924	.647
158–L	1.42	.14	.24	91.10	2.44	4.68	1,015	922	.599
25	1.36	.37	.13	81.91	11.00	4.42	1,087	1,001	.639
33	.25	1.00	.49	75.85	17.94	4.49	1,168	1,059	.674
35	.13	1.03	.39	72.02	21.16	5.29	1,187	1,078	.687
36	.65	.32	.33	77.98	15.22	5.51	1,134	1,022	.663
37	.24	1.21	.24	70.50	24.60	3.21	1,247	1,125	.702
40	.32	.81	.00	72.31	21.96	4.60	1,201	1,091	.691
39	.31	1.38	.46	72.06	21.37	4.41	1,209	1,087	.704

HOGSHOOTER.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Higher.	Lower.	Calculated sp. gr. Air=1.
26	1.24	0.31	0.47	88.94	3.33	5.66	1,076	920	0.612
27	.29	.89	.30	73.82	19.52	5.19	1,173	1,065	.687
28	.14	.83	.10	73.07	20.63	5.23	1,194	1,075	.686
29	1.55	.00	.39	91.82	2.35	3.98	1,022	927	.696
30	.50	1.28	.49	65.54	24.63	7.23	1,197	1,080	.661
32	.00	.38	.37	76.99	17.21	5.00	1,150	1,047	.664

WANN.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Higher.	Lower.	Calculated sp. gr. Air=1.
61	0.48	0.49	0.32	76.66	16.26	5.80	1,133	1,029	0.664
62	.36	.71	.18	77.19	15.19	5.68	1,123	1,032	.662
63	.16	.33	.17	76.67	16.69	5.98	1,136	1,039	.664
64	.45	.60	.46	74.00	17.02	7.47	1,121	1,043	.689

TABLE No. 38.—Data regarding the wells in the Bartlesville, Hogshooter and Wann fields from which were taken the samples listed in the foregoing table.

BARTLESVILLE.

LAB. No.	Location. Sec.	Location. R.	Location. Twp.	Name.	Well No.	Depth to top of sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date well was completed.	Rock pressure, in lbs. per sq. in.
237–L	24	12	25	Partin	3	884	....	2,350	3–1915	375
217–L	24	12	25	Partin	1	....	....	....	....	....
158–L	32	14	25	Lane	2	1,160	25	5,000	9–1913	150
25–L	33	14	26	Snell	2	Burgess sand............... January 31, 1914.				
33	12	14	26	Mary Kenner	3	....				
35	12	14	26	Ketcher	2	.... January 31, 1914.				
36	8	14	26	Bell	1	Bartlesville sand.				
37	12	14	26	J. Kenner	1	Bartlesville sand after blow.. January 31, 1914.				
40	12	14	26	J. Kenner	1	Bartlesville sand before blow, January 31, 1914.				
39	12	14	26	J. Kenner	1	Deep sand.................. January 31, 1914.				

HOGSHOOTER.

LAB. No.	Sec.	R.	Twp.	Name.	Well No.					
26	33	14	26	....	......	Burgess sand, sample submitted, Jan. 31, 1914.				
27	29	15	26	....	......	Burgess sand, sample submitted, Jan. 31, 1914.				
28	30	15	26	....	......	Burgess sand, sample submitted, Jan. 31, 1914.				
29	33	14	26	....	......	Burgess sand, sample submitted, Jan. 31, 1914.				
30	33	14	26	....	......	Bartlesville sand, sample submitted, Jan. 31, '14.				
32	20	15	26	....	......	Bartlesville sand, sample submitted, Jan. 31, '14.				

WANN.

LAB. No.	Sec.	R.	Twp.	Name.	Well No.					
61	34	14	28	Thompson	1	Sample submitted.......... February 1, 1914.				
62	2	14	27	Robinson's East	1	Sample submitted.......... February 1, 1914.				
63	3	14	27	Vann	2	Sample submitted.......... February 1, 1914.				
64	34	14	28	Cochran	2	Sample submitted.......... February 1, 1914.				

TABLE No. 39.—Analyses of gases from wells in Washington county, Tulsa county and the northwest corner of Wagoner county, Oklahoma.

LAB. No.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0° C., 760 mm., B.t.u. Higher.	Heat value, 0° C., 760 mm., B.t.u. Lower.	Calculated sp. gr. Air=1.
95–L	0.63	0.25	0.50	74.26	19.13	5.22	1,154	1,052	0.680
164–L	.75	.37	.24	91.66	4.46	2.50	1,069	970	.598
167–L	1.74	.24	.24	77.77	14.81	5.18	1,110	1,020	.667
159–L	.49	....	.39	89.34	5.77	3.98	1,059	963	.604
168–L	1.18	.52	.17	93.02	....	5.10	1,004	918	.592
161–L	.38	.10	.28	90.10	5.56	3.55	1,066	963	.602
165–L	.73	.14	.24	91.35	3.76	3.68	1,047	948	.596
160–L	.12	.12	.37	88.41	7.54	3.41	1,085	986	.609
169–L	.60	.44	.18	94.32	1.70	2.74	1,048	949	.584
170–L	3.29	.47	.12	88.88	4.48	2.74	1,043	944	.624
163–L	.15	.46	.00	63.92	24.10	11.47	1,141	993	.726
166–L	.18	.44	.00	68.56	19.45	11.35	1,104	986	.701

TABLE No. 40.—Location, depth, etc., of wells in Washington county, south of Bartlesville, Tulsa county, and the northwest corner of Wagoner county.

LAB. No.	Location. Sec.	Location. R.	Location. Twp.	Farm name.	Well No.	Depth to top of sand, feet.	Thickness of sand, feet.	Open flow, in 1,000 cu. ft.	Date well completed.	Rock pressure in lbs. pr. sq. in.
95–L	11	12	24	Keeler	......	....	....	....	....	....
164–L	27	13	21	Harkel	1	890	110	1,400	8–14	475
167–L	31	14	24	Hopkins	1	1,300	2	4,000	6–14	300
168–L	17	14	24	Brown	......	1,202	15	3,000	1–11	485
159–L	26	13	21	Blackmore	1	1,152	14	3,300	8–14	*560
161–L	35	13	21	Irons	1	800	105	8,000	6–14	480
165–L	3	13	20	Haskell	1	860	120	2,250	8–14	460
160–L	11	13	20	Palmer	1	820	120	7,750	10–13	490
169–L	36	13	21	Wuttermire	2	1,158	14	3,800	5–15	215
170–L	10	13	20	Haskell	1	865	115	2,500	9–15	425
163–L	15	15	19	Mons	1	858	12	8,000	1–15	405
166–L	21	15	19	Bilby	1	960	5	5,000	5–15	350

* This well had an open flow of 2,750,000 cubic feet and a rock pressure of 410 pounds, July 28, 1915.

Part IV.

VARIATIONS IN COMPOSITION.

ACCORDING to the United States Bureau of Mines, the supply of natural gas used in Pittsburgh, Pa., is subject to very little change in composition as time passes. For over one year the analyses showed a variation of a fraction of a percent in residue and a corresponding small change in B. t. u. Kansas gases show much more variation than this. Aside from the fact that the city supplies differ greatly, owing to the variation in quality of each field, the wells themselves show considerable variation.

Inasmuch as the different fields vary between extreme limits, the city supplies that come from one field for a while and then perhaps from another should be expected to change. An extreme case of this is that referred to in the account of the Sedan gas entering a line, page 88. The following table shows the composition of gases from cities, each using gas from the Kansas and northern Oklahoma fields.

TABLE No. 41.—Showing the composition of gases taken from the city supplies of several Kansas towns.

LAB. No.	City.	Date taken.	Company supplying city.	CO_2	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u., lower.
205–L	Chanute......	10–21–15	Local supplies.....	.63	.46	.34	91.25	2.97	4.34	941
227–L	Lawrence.....	10– 8–15	Kansas Natural...	.52	.47	.02	85.47	6.88	6.62	952
109–L	Iola..........	5–29–15	Wichita Natural...	.99	......	.42	78.27	10.84	9.50	945
1	Burden.......	2–17–14	Wichita Natural..	.93	.47	.31	79.26	10.33	9.17	944
2	Winfield......	2–18–14	Wichita Natural..	....	.47	.63	73.82	16.87	8.21	1,013
3	Udall.........	2–18–14	Wichita Natural..	....	......	.38	73.39	17.73	8.51	1,015
4	Wellington....	2–18–14	Wichita Natural..	....	.60	.31	75.53	15.42	8.15	1,005
8	Augusta......	2–20–14	Wichita Natural..	....	1.01	Tr.	75.68	10.97	12.32	956
9	Ottawa.......	2–21–14	Kansas Natural...	.40	.53	.54	88.93	4.68	4.93	948
10	Caney.......	....	Kansas Natural...	.94	.40	.27	79.90	9.77	8.72	941
11	Lawrence.....	2–23–14	Kansas Natural...	.72	.57	Tr.	86.42	7.23	5.06	969
1*a*	Wichita......	12–18–13	Wichita Natural..	.27	.76	.22	59.88	15.88	23.18	862
2*a*	Wellington...	12–18–13	Wichita Natural..	.20	.12	.36	65.18	10.20	23.96	808
4*a*	Arkansas City,	12–18–13	Wichita Natural..	.16	.17	.20	52.06	32.42	15.00	1,066
5*a*	Eldorado.....	12–18–13	Wichita Natural..	.53	......	.59	45.70	30.81	22.49	974
246–L	Topeka......	12–22–15	Kansas Natural...	.93	.12	......	85.42	7.51	6.01	957

Composition of Gases Taken at Different Times from City Supplies.

TABLE No. 42.—Lawrence city supply.

LAB. No.	Date taken.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u., lower.
30-L	5- 6-15	1.10	0.12	0.35	90.40	4.59	3.42	952
32-L	5-18-15	.53	.49	.24	91.70	4.52	2.51	968
33-L	5-18-15	.49	.54	.71	90.48	5.02	2.73	969
54-L	5-24-15	1.09	.49	.12	86.16	8.60	3.53	989
78-L	6- 4-15	.68	.32	.56	82.41	11.97	4.05	1,008
77-L	6- 2-15	.75	.25	.65	85.49	8.95	3.89	984
81-L	6-11-15	1.14	.19	.36	84.10	9.51	4.68	980
82-L	6- 7-15	.74	.30	.37	84.56	10.19	3.83	....
85-L	6-22-15	.64	.30	.94	82.43	10.50	5.18	982
87-L	7-13-15	.90	.15	.51	82.99	10.00	5.43	1,041
177-L	9- 8-15	....	....	....	90.60	5.12	2.53	968
178-L	9- 9-15	1.00	.42	.24	89.80	4.89	3.65	961
187-L	9-15-15	....	....	....	87.62	7.75	3.39	970
188-L	9-16-15	.19	.54	.36	84.74	8.46	5.68	974
189-L	9-17-15	.49	.49	.37	84.02	9.49	5.10	983
198-L	10-19-15	.49	.24	.10	81.00	10.75	7.42	968
227-L	10- 8-15	.52	.47	.02	85.47	6.88	6.62	952
233-L	11-19-15	.84	.09	.21	81.82	9.70	7.33	953
234-L	12- 1-15	.86	.07	.12	85.50	7.24	6.20	951
245-L	1- 5-16	.69	....	.20	80.45	10.55	8.12	969
249-L	1-28-16	....	....	....	81.90	8.35	8.95	936
250-L	1-29-16	....	....	....	83.22	7.98	7.18	942

TABLE No. 43.—Hutchinson city supply.

LAB. No.	Date taken.	Time.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u., lower.
....	2-17-14	8 a. m.	0.51	0.50	0.76	65.83	16.72	15.67	933
....	2-17-14	12 noon	.18	.37	.36	71.70	13.32	14.11	929
....	2-17-14	4 p. m.	.34	.42	.43	70.43	13.66	14.73	923
....	2-18-14	8 a. m.	.25	.55	.20	69.25	14.84	14.94	934
....	2-18-14	12 noon	.37	.36	.18	71.16	13.80	14.16	932
....	2-18-14	4 p. m.	.16	.49	.33	70.03	13.03	15.97	910
....	2-15-14	12 noon	.46	.69	.81	56.81	22.29	18.92	932
....	2-16-14	8 a. m.	.54	....	.00	54.42	21.61	23.41	907
....	2-16-14	12 noon	.36	.24	.48	56.28	23.67	18.96	938
....	2-16-14	4 p. m.	.53	.40	.26	59.14	21.31	18.37	939
....	2-15-14	4 p. m.	.59	.78	.00	63.21	19.67	15.73	958
123	....	....	.00	.41	.27	55.10	15.54	28.66	807
124	....	....	.00	.41	.27	58.59	12.67	28.06	791
....	2-10-14	12 noon	.24	.71	.35	57.95	20.03	20.75	917
....	2-10-14	4 p. m.	.46	.70	.23	66.20	17.24	15.17	949
....	2-11-14	8 a. m.	.35	.47	.46	59.10	18.77	20.86	903
....	2-11-14	12 noon	.34	.24	.23	62.56	16.32	20.28	890
....	2-11-14	4 p. m.	.37	.37	.24	59.91	19.45	19.67	920
....	2-12-14	8 a. m.	.36	.60	.24	65.64	16.70	16.47	932
....	2-12-14	12 noon	.22	.66	.65	51.75	24.60	22.09	935
....	2-12-14	4 p. m.	.76	.57	.19	56.23	22.03	20.20	933
....	2-13-14	8 a. m.	.15	.94	.27	59.09	20.19	19.38	938
....	2-13-14	12 noon	.00	.75	1.87	46.91	23.67	26.82	874
....	2-13-14	12 noon	.00	.82	.00	51.52	26.01	21.69	960
....	2-13-14	4 p. m.	.00	.37	.38	51.05	26.44	21.78	956
....	2-14-14	8 a. m.	.16	.15	1.10	55.49	22.54	20.55	928
....	2-14-14	12 noon	.32	.64	6.67	38.90	16.90	36.56	674
....	2-14-14	12 noon	.47	.94	.00	57.37	24.88	16.35	*998
....	2-14-14	4 p. m.	.45	.31	1.24	59.80	18.45	19.74	901

* Air free.

TABLE No. 44.—Wichita city supply.

Lab. No.	Date taken.	Time.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u., lower.
....	2-19-14	12 noon	0.37	0.64	0.27	66.90	12.45	19.40	872
....	2-19-14	6 p. m.	.59	.39	.58	69.08	14.21	15.15	919
....	2-20-14	6 a. m.	.40	.29	.30	60.81	19.45	18.77	928
....	2-20-14	6 a. m.	.19	.38	.37	67.22	15.91	15.92	933
....	2-20-14	12 noon	.51	.09	.25	62.60	17.47	19.08	908
....	2-20-14	6 p. m.	.33	.50	.32	67.25	16.17	15.44	937
....	2-21-14	6 a. m.	.08	.40	.32	64.14	18.52	16.53	946
....	2-21-14	6 p. m.	.16	.17	.48	66.78	14.22	18.21	962
....	2-14-14	6 a. m.	.53	.27	.26	60.01	21.82	17.10	961
....	2-14-14	12 noon	.42	.57	.43	60.39	19.91	18.30	936
....	2-14-14	6 p. m.	.50	.25	.25	63.37	17.70	17.94	922
....	2-15-14	6 a. m.	.27	.20	.60	56.16	22.08	20.69	927
....	2-15-14	12 noon	.53	.20	.46	60.90	20.88	17.05	952
....	2-15-14	6 p. m.	.67	.26	.53	59.76	21.66	17.12	955
....	2-16-14	6 a. m.	.15	.29	.20	76.15	9.07	14.14	897
....	2-16-14	12 noon	.67	.27	.67	68.54	14.43	15.42	916
....	2-16-14	6 p. m.	.65	.26	.26	68.54	14.76	15.55	921
....	2-17-14	6 a. m.	.27	.27	.40	69.05	13.74	16.27	909
....	2-17-14	6 p. m.	.53	.40	.39	71.07	12.80	14.82	914
....	2-18-14	6 a. m.	.13	.39	.78	67.80	13.76	17.15	899
....	2-18-14	12 noon	Tr.	.30	1.20	77.26	9.47	11.79	915
....	2- 9-14	6 p. m.	.45	.56	.22	63.48	18.04	17.28	934
....	2-10-14	7 a. m.	.12	.60	.59	60.08	21.35	17.24	959
....	2-10-14	12 noon	.71	.47	.47	66.52	16.19	15.65	930
....	2-10-14	6 p. m.	.36	.72	.24	64.71	17.66	16.28	942
....	2-11-14	6 a. m.	.25	.37	.13	61.81	18.52	18.94	923
....	2-11-14	12 noon	.40	.54	.81	62.01	18.81	17.42	932
....	2-11-14	6 p. m.	.26	.27	.40	60.77	20.64	17.65	948
....	2-12-14	6 a. m.	.00	.27	.28	60.39	18.47	20.80	907
....	2-12-14	12 noon	.39	.52	.26	61.50	19.40	17.94	938
....	2-13-14	6 a. m.	.00	.49	.00	60.17	19.38	19.97	924
....	2-13-14	12 noon	.29	.28	.29	53.94	23.49	20.70	941
....	2-13-14	6 p. m.	.16	.57	3.01	49.58	18.55	28.15	809

In this connection the Wichita Natural Gas Company was asked to submit samples of gas taken at close intervals from one well, which had been previously analyzed, in order to show whether the character of the gas from this well would change. Some of the samples came to the laboratory so highly contaminated with air that the results may not be entirely reliable, but that there is considerable variation seems quite certain.

TABLE No. 45.—Samples taken at different times from the O. Feltham well, section 10, range 28, township 4, Butler county.

LAB. No.	Date submitted.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	Heat value, 0°C., 760 mm., B. t. u., lower.
178–L	7–19–15	0.00	0.64	3.00	72.55	14.43	12.37	960
179–L	7–26–15	.00	.12	.12	71.80	15.22	12.86	960
181–L	8– 2–15	.12	.26	.90	74.70	13.98	10.93	966
182–L	8– 9–15	.34	.18	.70	74.83	12.70	11.92	943
183–L	8–16–15	.26	.00	7.47	77.90	13.09	8.77	972
184–L	8–23–15	.11	.10	.29	72.50	8.69	18.60	850
185–L	8–30–15	.00	.21	8.17	75.80	12.40	11.59	948
186–L	9– 7–15	.00	.00	1.94	75.04	15.37	9.59	991
241–L*	9–21–15	.00	.00	.24	59.18	23.46	17.72	975
242–L	10–20–15	.00	.13	.28	68.21	19.15	12.53	994
242–L	10–20–15	....	....	.12	70.57	18.13	11.31	995
243–L	11–20–15	.00	.47	.12	70.26	15.87	13.37	951
244–L	12–13–15	.00	.00	....	68.14	15.00	16.86	917

* Labeled Feltham No. 4. Gravity: 241–L, .691; 242–L, .690; 243–L, .691. (Determined.)

OPEN FLOW OF O. FELTHAM WELL.

DATE.	Pressure after 15 minutes of open flow.	Open flow, in 1,000 cu. ft.
June 30, 1915	427	1,470
August 31, 1915	390	1,300
September 30, 1915	380	1,200
October 31, 1915	372	1,200
November 30, 1915	367	1,200

Variations in the Composition of North Osage Gas Caused by Dilution With Sedan Gas.

The character and effect of the low-grade Sedan gas is shown by a series of tests conducted by one of the authors for the Wichita Natural Gas Company. This company was supplying Hutchinson, Wichita and other towns in that locality from the North Osage field. The North Osage gas is very good in quality (see Table No. 36), and usually it is better than most dry gases in Kansas. As soon as the Sedan field was drilled in this company laid pipe lines and began to take out the gas. It was carried to the same consumers along with the North Osage supply. Almost immediately the consumers began to complain about the gas bills, and these complaints became so numerous that the company began an investigation. Samples of the gas were finally submitted to the University of Kansas for analysis, and it was learned that the difficulty lay in the poor quality of the gas from Sedan.

In order to determine the effect of diluting the North Osage gas with that from Sedan, a series of samples were taken

at intervals of three hours for 120 hours at the town of Cambridge, which is about 40 miles from the place where the Sedan gas enters. These were analyzed, and the results are shown in the following tables.

Nine hours after the admission of Sedan gas the B. t. u. value dropped from 920 to 885, and three hours later to 875. Then nine hours after the Sedan gas was cut off the heating value came back to normal. This variation was repeated throughout the 120 hours run, except the sample taken at midnight on January 31, which shows a decided break. This break was caused either by a pocket of gas which was pushed along, or by improper labeling of the sample. It is to be regretted that two of the samples taken at three p. m. and six p. m. on February 2 were broken in transit, but the probabilities are that they would have shown the same variations as outlined above.

The curve (Fig. 2) which is plotted between time and B. t. u.'s will present more clearly the results incorporated in the table. If the sample taken on the 69th hour be eliminated it is interesting to note how slowly the line clears of Sedan gas at this time. This is explained by the fact that the total volume of gas passing through was smaller than before.

The company, after this investigation, discontinued the use of Sedan gas.

The cause of the trouble in this case, and in all such cases, is not that this gas will not burn, but that the change in composition and heating value requires a different adjustment of the burners. The real trouble lies in the variation of the heating value rather than in the low heat value of the Sedan gas, or of the mixture.

The heating value of this poorer gas is about the same as that of the ordinary artificial gas sold in many cities, and the gas will burn in a very satisfactory manner. However, on account of the low velocity of combustion of methane as compared with some of the constituents present in artificial gas, this gas, while possessing about the same heating value per cubic foot, will not burn as satisfactorily as artificial gas. The tendency to "blow" will be much greater.

TABLE No. 46.—Analyses of mixture of North Osage and Sedan gas.

JANUARY 29, 1915.

NUMBER	1	2	3	4	5	6	7	8
TIME	12 mid.	3 a. m.	6 a. m.	9 a. m.	12 noon	3 p. m.	6 p. m.	9 p. m.
Carbon dioxide	0.77	1.22	0.99	1.37	1.19	0.61	0.79	0.95
Heavy hydrocarbons	0.96	1.41	1.12	1.44	0.75	0.81	0.86	1.12
Oxygen	0.38	0.85	0.37	0.65	0.51	0.64	0.55	0.58
Methane	80.80	77.81	78.83	78.41	77.49	77.52	76.26	78.50
Ethane	7.08	8.29	8.11	7.89	7.17	6.56	7.48	8.37
Residue	10.01	10.57	10.55	10.21	12.92	13.88	14.09	10.49
Total	100.00	100.15	99.97	99.97	100.03	100.02	100.03	100.01
B.t.u	922	918	920	917	885	875	879	901

JANUARY 30, 1915.

Carbon dioxide	0.76	1.11	1.09	1.57	0.76	1.07	1.03	0.40
Heavy hydrocarbons	0.68	0.69	0.32	0.18	0.72	1.06	0.35	0.47
Oxygen	0.58	1.00	0.46	0.52	0.62	0.64	0.57	0.44
Methane	77.59	76.50	78.84	79.38	79.96	80.02	81.24	79.32
Ethane	9.70	9.31	9.31	8.53	4.49	4.50	4.08	6.08
Residue	10.68	11.39	9.97	9.78	13.46	12.69	12.68	13.50
Total	99.99	100.00	99.99	99.96	100.01	99.98	99.95	100.21
B.t.u	928	911	928	917	860	867	861	879

JANUARY 31, 1915.

Carbon dioxide	0.79	1.35	1.03	0.82	0.92	1.48	1.07	0.81
Heavy hydrocarbons	1.15	0.67	1.03	1.21	0.54	0.84	1.00	0.78
Oxygen	0.30	0.64	0.30	0.21	0.07	0.35	0.18	0.71
Methane	73.54	77.86	78.53	75.14	79.25	73.34	75.71	72.15
Ethane	11.73	8.72	8.23	10.47	9.11	7.77	6.75	9.35
Residue	12.49	10.75	10.80	12.16	10.11	16.22	15.30	16.19
Total	100.00	99.99	99.92	100.01	100.00	100.00	100.01	99.99
B.t.u	932	914	918	926	932	856	864	921

FEBRUARY 1, 1915.

Carbon dioxide	1.20	0.51	0.87	1.08	1.32	0.79	1.04	1.03
Heavy hydrocarbons	0.79	1.10	0.83	0.73	1.01	0.52	0.66	0.66
Oxygen	0.24	0.41	0.34	0.73	0.31	1.24	0.24	0.41
Methane	70.41	73.02	72.10	77.92	77.41	71.79	74.78	74.43
Ethane	9.99	8.25	9.22	9.04	9.76	6.88	7.99	8.46
Residue	17.38	16.72	16.66	10.49	10.18	18.77	15.24	14.98
Total	100.01	100.01	99.92	99.99	99.99	99.99	99.95	99.97
B.t.u	866	866	868	922	933	*821 (864)	871	876

*Calculated to average oxygen basis.

FEBRUARY 2, 1915.

Carbon dioxide	1.13	1.05	0.96	1.07	....	....	0.83	0.95
Heavy hydrocarbons	0.84	1.42	1.18	0.52	*.......	....	0.63	0.70
Oxygen	0.26	0.32	0.44	0.52	....	....	0.48	0.56
Methane	75.33	76.91	78.26	79.49	....	....	74.73	77.23
Ethane	11.04	9.70	8.97	8.56	....	....	9.26	9.70
Residue	11.41	10.50	10.20	9.93	....	....	14.07	10.87
Total	100.01	99.90	100.01	100.01	....	....	100.00	100.01
B.t.u	932	934	930	924	....	....	892	925

*Broken in transit. No hydrogen indicated in any of the above analyses. Carbon monoxide not tested for.

TABLE No. 47.—Mixtures of North Osage and Sedan gases giving preceding analyses.

JANUARY 29, 1915.

	Net amount entering line south, in 1,000 cu. ft.	Sedan field.	Total gas entering line, in 1,000 cu. ft.	Heating value, B.t.u.	Percentage of Sedan gas entering line.
12 mid. to 3 a. m.	1,916	0	1,916	922	0
3 a. m. to 6 a. m.	1,594	0	1,594	918	0
6 a. m. to 9 a. m.	794	88	882	920	9.98
9 a. m. to 12 noon	1,551	255	1,806	917	14.12
12 noon to 3 p. m.	1,635	254	1,889	885	13.45
3 p. m. to 6 p. m.	1,638	254	1,892	875	13.42
6 p. m. to 9 p. m.	1,635	0	1,635	879	0
9 p. m. to 12 mid.	1,447	0	1,447	901	0

JANUARY 30, 1915.

12 mid. to 3 a. m.	859	0	859	928	0
3 a. m. to 6 a. m.	862	0	862	911	0
6 a. m. to 9 a. m.	1,174	83	1,257	928	6.60
9 a. m. to 12 noon	1,442	254	1,696	917	14.97
12 noon to 3 p. m.	1,385	256	1,641	860	15.60
3 p. m. to 6 p. m.	1,373	255	1,628	868	15.66
6 p. m. to 9 p. m.	1,156	0	1,156	861	0
9 p. m. to 12 mid.	334	0	334	879	0

JANUARY 31, 1915.

12 mid. to 3 a. m.	193	0	193	932	0
3 a. m. to 6 a. m.	557	0	357	914	0
6 a. m. to 9 a. m.	1,449	87	1,536	918	5.66
9 a. m. to 12 noon	1,268	260	1,528	926	17.02
12 noon to 3 p. m.	1,274	256	1,530	932	16.73
3 p. m. to 6 p. m.	1,386	257	1,642	856	15.64
6 p. m. to 9 p. m.	1,475	0	1,475	864	0
9 p. m. to 12 mid.	1,493	0	1,493	921	0

FEBRUARY 1, 1915.

12 mid. to 3 a. m.	1,433	0	1,433	866	0
3 a. m. to 6 a. m.	945	0	945	866	0
6 a. m. to 9 a. m.	1,201	131	1,332	868	9.82
9 a. m. to 12 noon	1,609	252	1,861	922	13.54
12 noon to 3 p. m.	1,876	251	3,127	933	11.80
3 p. m. to 6 p. m.	1,919	251	2,170	864	11.56
6 p. m. to 9 p. m.	1,931	0	1,931	871	0
9 p m. to 12 mid.	1,932	0	1,932	876	0

FEBRUARY 2, 1915.

12 mid. to 3 a. m.	1,367	0	1,367	932	0
3 a. m. to 6 a. m.	784	0	784	934	0
6 a. m. to 9 a. m.	1,284	171	1,455	930	11.75
9 a. m. to 12 noon	2,168	246	2,414	924	10.19
12 noon to 3 p. m.	2,230	248	2,478	....	10.00
3 p. m. to 6 p. m.	1,705	248	1,952	....	12.70
6 p. m. to 9 p. m.	1,517	0	1,517	892	0
9 p. m. to 12 mid.	1,228	0	1,228	925	0

Variation in Pressure.

In general it may be stated that the consumers of natural gas in eastern Kansas have never had cause for complaint so far as the quality of the gas is concerned. The causes of practically all the complaint of high gas bills, no heat in the gas, air mixed with the gas, etc., are variations in the gas pressure and the low gas pressure so common in cold weather. A few pressure charts are given to illustrate this variation at different times of the day and year.

One effect of the wide variation in pressure is shown in the following table, giving the relative amounts of gas that will pass through a fixed opening when the gas is under the pressure indicated:

Excess pressure, above atmospheric, inches of water.	Ratio number, volume of gas.
2	1.00
4	1.75
6	2.20
8	2.62
10	3.00
12	3.37
14	3.67
16	4.00
18	4.27
20	4.53
22	4.78
24	5.02
26	5.26
28	5.49

The opening used for this data would pass about 5 cubic feet per hour with a pressure of 12 inches of water, which is about the quantity used by an ordinary gas light. While no great accuracy is claimed for the values given, they are not far from correct.

The data shows that about four times as much gas will pass under 16 inches of water pressure as under 2 inches. It is very common for the pressure to vary between these limits in the winter, and if a heater or other gas appliance is burning in the evening when the gas pressure is equal to two inches of water and allowed to burn through the night without adjustment, the gas consumed will be much greater after the pressure comes up later in the night.

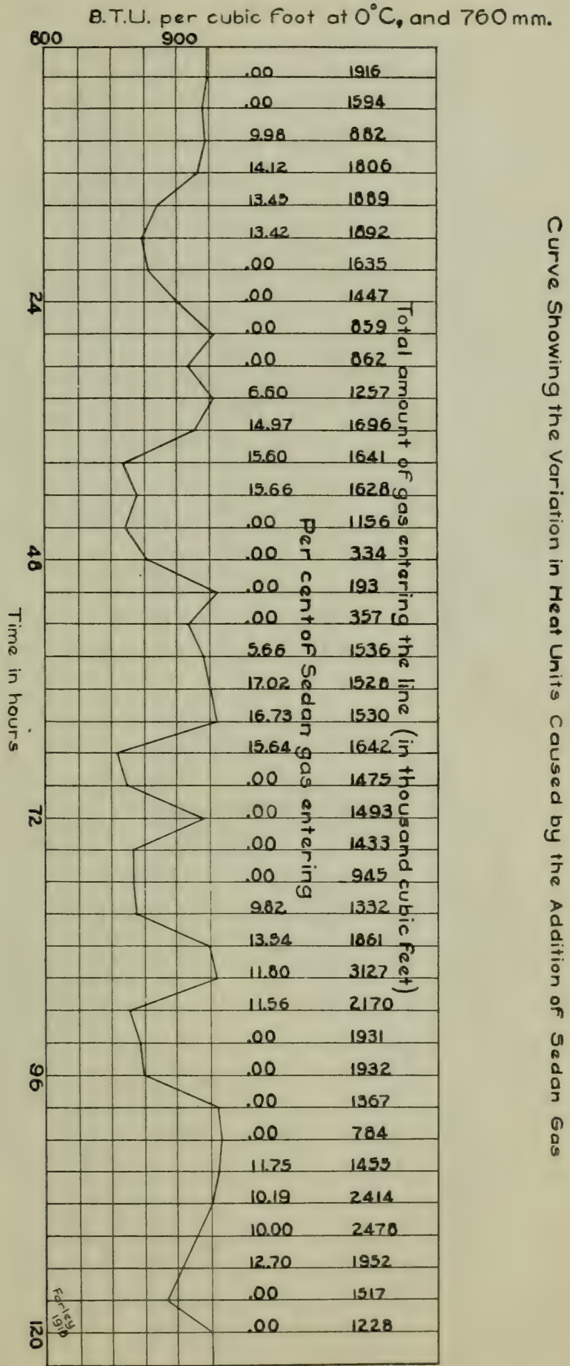

Curve Showing the Variation in Heat Units Caused by the Addition of Sedan Gas
B.T.U. per cubic foot at 0°C, and 760 mm.
800
900
Time in hours
24
48
72
96
120
Per cent of Sedan gas entering
Total amount of gas entering the line (in thousand cubic feet)
.00 1916
.00 1594
9.98 882
14.12 1806
13.45 1889
13.42 1892
.00 1635
.00 1447
.00 859
.00 862
6.60 1257
14.97 1696
15.60 1641
15.66 1628
.00 1156
.00 334
.00 193
.00 357
5.66 1536
17.02 1528
16.73 1530
15.64 1642
.00 1475
.00 1493
.00 1433
.00 945
9.82 1332
13.54 1861
11.80 3127
11.56 2170
.00 1931
.00 1932
.00 1367
.00 784
11.75 1455
10.19 2414
10.00 2478
12.70 1952
.00 1517
.00 1228
Farley 1910

FIG. 4.

Gas under an excess pressure of two inches of water contains within about three percent as many heat units per cubic foot as when under an excess pressure of sixteen inches of water. However, this excess over the atmospheric pressure makes a great difference in the rate at which the gas can be burned with the different pressures, as shown in the preceding table, and with the very low pressures it cannot be burned fast enough to give satisfaction.

Radiation of heat from cooking utensils, gas appliances, etc., takes place according to well-known laws, and depends upon the difference in temperatures between the room and such utensils or appliances. The greater the difference in temperatures the faster the heat radiates. Heat is supplied at a certain rate, and with the very low pressures this may be quite slowly, so that it may easily happen that the heat is radiated as fast as it can be supplied, before the desired temperatures for cooking or baking is reached. Even if it is possible to finally reach the desired temperature, it takes much longer to do so, with the result that more gas is burned than would have been necessary if the gas could have been burned faster and for a shorter time.

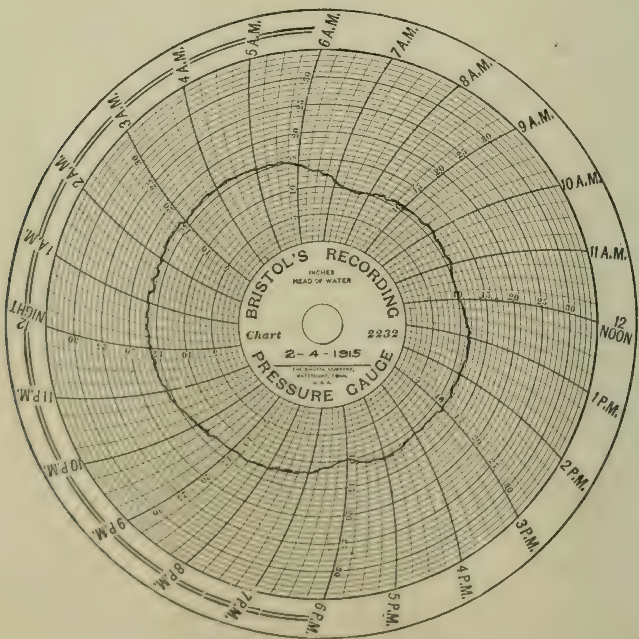


FIG. 5.

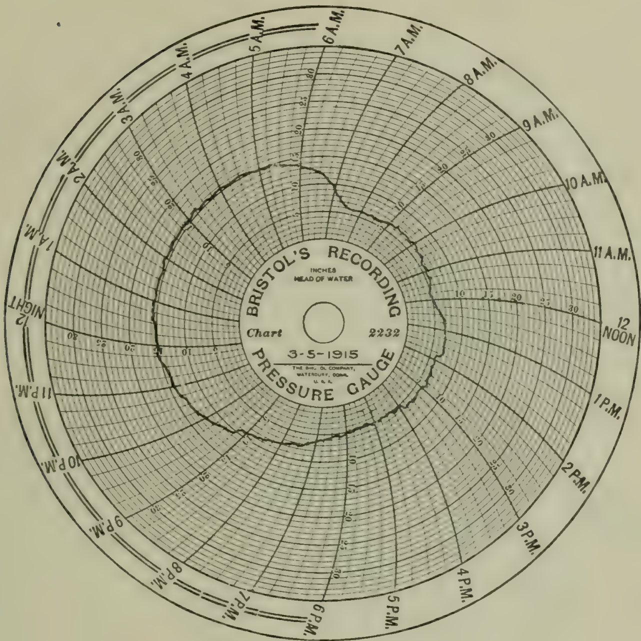

BRISTOL'S RECORDING
INCHES
HEAD OF WATER
Chart
2232
3-5-1915
PRESSURE GAUGE
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.

FIG. 6.

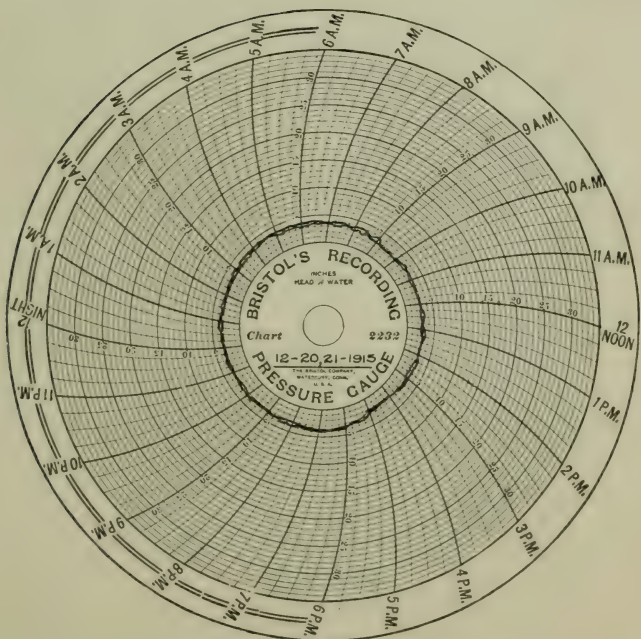

BRISTOL'S RECORDING
INCHES
HEAD OF WATER
Chart
2232
12-20,21-1915
PRESSURE GAUGE
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.

FIG. 7.

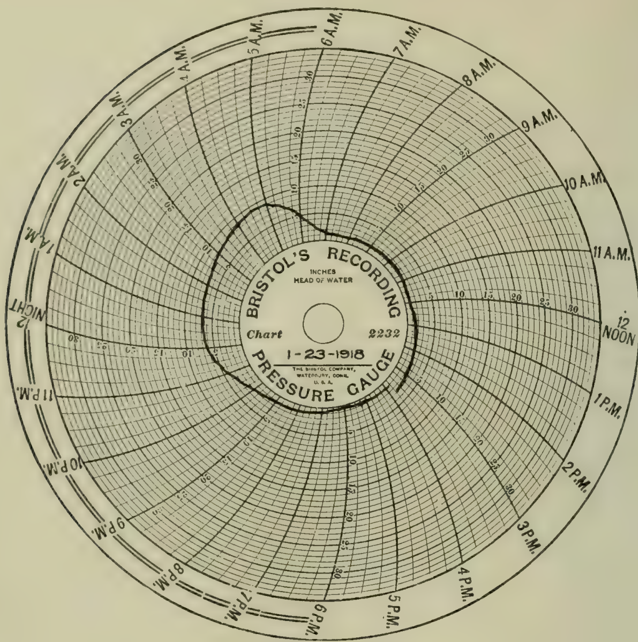

BRISTOL'S RECORDING
INCHES
HEAD OF WATER
Chart 2232
1-23-1918
PRESSURE GAUGE
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.

FIG. 8.

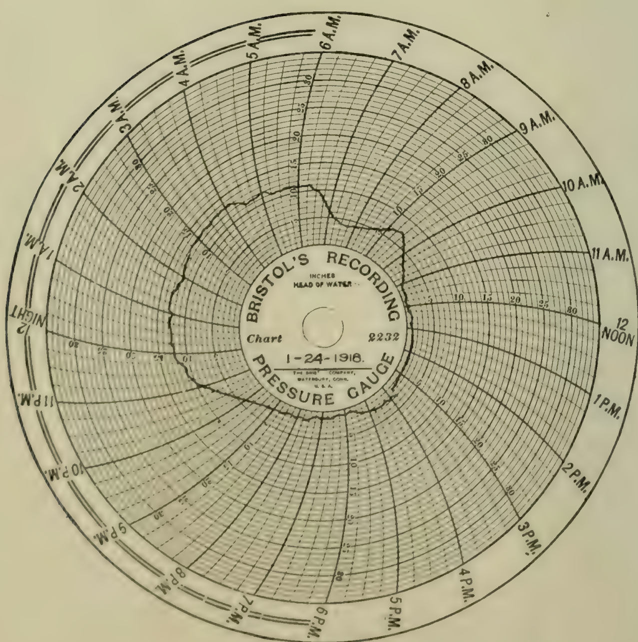

BRISTOL'S RECORDING
INCHES
HEAD OF WATER
Chart 2232
1-24-1918.
PRESSURE GAUGE
12 NOON
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
8 P.M.
9 P.M.
10 P.M.
11 P.M.
12 NIGHT
1 A.M.
2 A.M.
3 A.M.
4 A.M.
5 A.M.
6 A.M.
7 A.M.
8 A.M.
9 A.M.
10 A.M.
11 A.M.

FIG. 9.

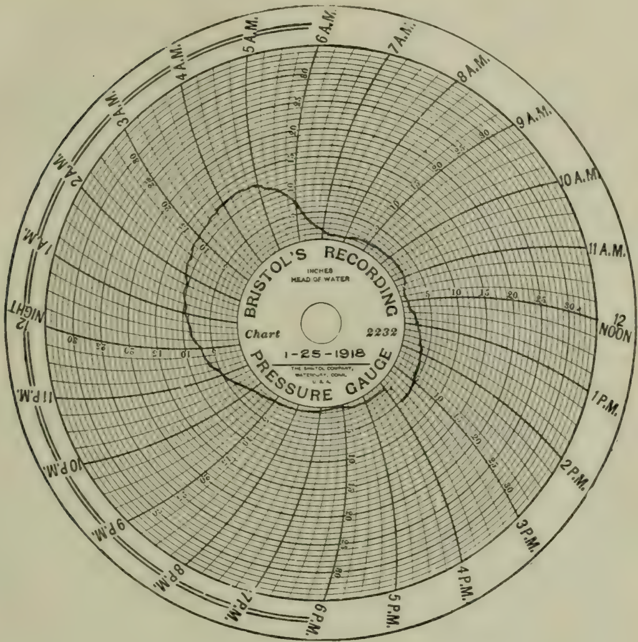


FIG. 10.

Part V.

GAS ANALYSES.

TABLE No. 48.—Analyses of Kansas and Oklahoma gases, made by Cady & McFarland in 1908.

CITY.	O_2.	CO_2.	HHC.	CO.	CH_4.	C_2H_6.	Total paraffin.	H_2.	He.	N_2.
Dexter	0.20	0.00	0.00	0.00	14.85	0.41	15.22	Trace	1.84	82.70
Fredonia	Trace	.61	.12	.00	82.25	.00	82.25	.00	.616	16.40
Augusta	.00	.00	.77	.00	79.10	7.44	86.54	.00	.25	12.44
Iola	.23	.00	......	.00	94.50	.00	94.50	Trace	.183	5.08
Blackwell, Okla	.00	.00	.61	.00	83.40	10.31	93.71	.33	.159	6.39
Paola	.40	.70	.00	.00	98.00	.00	98.00	.00	.0093	.88

It should be of interest to include here the composition of other gases in this country and in foreign fields, and for the sake of comparison a few of these are given. The high content of CO_2 in some of the California gases should be noted.

TABLE No. 49.—Analyses of other American gases.

Lab. No.	Analyst.	Field.	Location. Sec.	Location. R.	Location. Twp.	CO_2.	HHC.	O_2.	CH_4.	C_2H_6.	Res.	B.t.u.
5864	G. A. Burrell	Loco, Okla	15	5W	3S	0.20	0.00	0.00	75.10	8.50	16.20	958
5865	G. A. Burrell	Loco, Okla	15	5W	3S	.00	.00	.00	80.20	11.10	8.70	1,061
586	Bureau of Mines	Duncan, Okla	12	6W	1N	.40	.00	.00	91.90	4.10	3.60	1,055
1	H. C. Allen	Dallas, Tex	....	....	....	.12	.48	.36	47.93	12.64	38.35	687
19	H. C. Allen	Fort Worth, Tex	*.......	....	....	.00	.63	Trace	46.40	13.96	39.01	700
20	H. C. Allen	Fort Worth, Tex	†.......	....	....	.26	.51	Trace	52.60	10.31	36.12	696
21	H. C. Allen	Fort Worth, Tex	*.......	....	....	.00	.26	.13	50.01	11.67	37.42	689
22	H. C Allen	Fort Worth, Tex	†.......	....	....	.00	.52	.78	48.66	10.89	39.16	667
9206	Irving C. Allen	Santa Marie, Cal	....	....	....	15.50	....	.20	62.70	20.20	1.40	1,044
10576	B. B. Grinnell	Torrey, Cal	....	....	....	6.80	.00	.00	54.20	35.60	3.40	1,240
1000	Irving C. Allen	McKi.trick, Cal	29	22E	30S	30.40	.00	.00	66.20	1.00	2.40	1,019
10578	J. Collins	Fullerton, Cal	....	....	....	1.40	.00	.00	85.80	10.90	....	1,117
......	....	Fort Smith, Ark	....	....	....	.93	‡........	.13	96.12	.00	....	966

*Low Pressure Station. †High Pressure Station. ‡H, .05; CO, .08; C_2H_2, .02.

TABLE No. 50.—Foreign gases.

COUNTRY.	Field collected from.	CO_2.	O_2.	CH_4.	C_2H_6.	N_2.	Analyst.
Austria.......	Wells....................	1.30	0.60	97.10	0.00	1.00	J. Frank.
Hungary......	Unutilized wells...........	.65	.00	92.05	.00	7.30	....
Germany.....	Negengamme, near Hamburg	.30	.00	91.50	2.10	4.60	Dr. Sehertel.
New Zealand..	Waivarapa Akitio Dist. Gas Spring..................	.00	12.00	35.3	17.60	35.1	Dr. Meclaurin.
Russia........	Samara well at Nev. Usensk.	1.17	4.22	53.45	.40	40.86	....
Canada.......	Elgin, No. 1..............	....	....	84.10	10.80	5.10	*..............
Canada.......	Holbimand, No. 1.........	....	....	79.4	14.30	6.30	*..............
Canada.......	Welland, No. 3............	....	....	82.10	13.50	4.40	*..............

*Analyses taken from "The Chemical Composition of Natural Gas Found in Ontario," by G. P. Mickle.

COST COMPARISON.

Analyses and Comparative Heating Values of Natural Gas and Coals.

In view of the recent publicity given the fuel question in all parts of the country, the following data, prepared for the Public Utilities Commission of Kansas and used with their consent, is believed to be of considerable general interest. The coals given are typical of those sold in the territory supplied with natural gas, and the samples used were fairly representative, with the exception of the Leavenworth sample, which was rather more of a selected sample. The matter of efficiency, cleanliness, convenience and all personal factors are not taken into account in the figures given, only the actual total number of heat units obtained being considered. The prices per ton given for the coals are about the average retail prices at the present time.

LAWRENCE CITY SUPPLY OF NATURAL GAS.—ANALYSES.

Lab. No	1238	1249	1250	1260	1261
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*
Carbon dioxide	0.23	0.77	0.85	0.51	0.72
Oxygen	0.00	0.00	0.45	0.55	0.17
Methane	85.80	88.44	89.95	91.24	92.50
Ethane	7.22	5.74	4.97	3.52	3.11
Residue	6.75	5.05	3.98	4.18	3.50
Total	100.00	100.00	100.00	100.00	100.00
Heating value.*					
Gross	1,048	1,049	1,050	1,037	1,043
Net	953	954	954	942	948

Average gross heating value, corrected for humidity and to 60° F. and 30 in., 993 B.t.u.
*Calculated to 0° C., and 760 mm. pressure, B.t.u.

ANALYSES OF COALS.

Lab. No	1,251	1,252	1,253	1,254
Kind of coal	Arkansas Semi-anthracite.	Burlingame.	Briquette.	Cherokee.
Price per ton	$10.00	$6.60	$10.00	$6.60
Proximate analysis:	*Percent.*	*Percent.*	*Percent.*	*Percent.*
Water	0.45	7.67	0.56	1.81
Volatile	18.07	39.62	21.21	36.11
Fixed carbon	73.48	38.44	63.88	52.35
Ash	8.00	14.27	14.35	9.73
Total	100.00	100.00	100.00	100.00
Heating value per pound, B.t.u	14,133	10,972	13,061	13,341
Comparative price of gas per 1,000 cu. ft	35.13 cts.	29.80 cts.	38.02 cts.	24.56 cts.
Lab. No	1,255	1,256	1,257	1,258
Kind of coal	Arkansas anthracite.	Smithing.	Leaven-worth.	Illinois.
Price per ton	$11.00	$15.00	$6.60	$7.75
Proximate analysis:	*Percent.*	*Percent.*	*Percent.*	*Percent.*
Water	1.45	0.58	5.95	7.76
Volatile	15.25	22.42	39.15	43.60
Fixed carbon	75.36	70.08	48.11	43.00
Ash	7.94	6.92	6.79	5.64
Total	100.00	100.00	100.00	100.00
Heating value per pounds, B.t.u	13,560	14,339	12,718	12,375
Comparative price of gas per 1,000 cu. ft*	40.64 cts.	54.91 cts.	25.76 cts.	31.08 cts.

*The prices given for gas are those that should be paid in order that each heat unit from the gas would cost the same as a heat unit from the respective coal at the indicated price.

SUMMARY.

1. A general survey of the field, showing the composition of gases found in most localities.

2. A modification of apparatus for analyses of gases is described.

3. The gases of the Mid-Continental field have been shown to vary between wide limits—99 percent to 10 percent—as to percentage of hydrocarbons and nitrogen present, and consequently in heating values. The maximum percentage of CO_2 found was slightly over 4 percent.

4. The shallower gases are poorer in quality than deeper ones found in the same locality.

5. Analytical data showing the effect of mixing some of the poorer gases with good gas.

6. The principal causes of complaint of the domestic consumer, outside of his own responsibility, is low pressure, variation in pressure, poor quality, and variation in quality. No air is ever intentionally mixed with the gas by pipe-line or distributing companies.

7. Shows possibilities of gases of various localities for recovery of gasoline by absorption processes.

8. The possibility of utilizing chemical means as well as geological means in oil and gas development work has been pointed out.

BULLETIN OF THE UNIVERSITY OF KANSAS

VOL. XXIII JUNE 15, 1922 No. 12

ENGINEERING BULLETIN No. 12

pt. 1

INDUSTRIAL DEVELOPMENT OF KANSAS

SECTION I

BY

P. F. WALKER, M. M. E.

Professor of Industrial Engineering and
Dean of the School of Engineering

UNIVERSITY ENGINEERING EXPERIMENT STATION
LAWRENCE, KANSAS

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The Engineering Experiment Station of the University of Kansas was established by action of the Regents, March 17, 1908. It is the purpose of the Station to carry on investigations of various problems in engineering lines which are of interest to engineers and to those engaged in industrial enterprises in the state.

The work of the Station is controlled by a staff composed of the Chancellor of the University and the heads of Engineering Departments.

The Station designs to issue bulletins, of which this is the twelfth number, containing the results of investigations that may be undertaken. There are several such now under way and others are contemplated. It is also designed to issue from time to time compilations of the results of investigations by engineers, manufacturing establishments, other institutions or government laboratories, for which there may be special need in this section of the country.

The numbers of the Experiment Station Bulletin will be in continuous series and will be found just above the title.

Correspondence regarding these bulletins or the work of the Station may be addressed to the Director of the Engineering Experiment Station, University of Kansas.

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INTRODUCTION.

THIS report is the outcome of an investigation that has extended over several years, during which the author has visited every city in the state where conditions have appeared to be favorable to the development of manufacturing or where industries have already been developed in one or more lines. The general purposes in view have been three-fold; namely:

(*a*) To bring to the attention of business and commercial interests of Kansas, and to all interested individuals, the importance which attaches to a systematic development of the manufacturing industries.

(*b*) To present the dominant characteristics of those forms of manufacturing which are best suited to the needs of the state, and which may serve best as upbuilding agencies.

(*c*) To place in form convenient for reference information respecting present industries and the advantages offered by the state generally, and by individual cities in particular, for further development; and to bring this information to the attention of business interests in all parts of the country.

There is being evolved gradually in this country the conception of an industrial system worked out in accordance with the natural economic forces. Such a system takes cognizance of markets, both domestic and foreign, sources of raw and process materials, economy of transportation in the larger sense of holding the volume of traffic in necessary commodities to a minimum, and stabilizing the food-producing power of the soil on a basis of continued growth in accordance with increases in population.

It is an axiom needing no comment beyond the mere mention, that the single-industry community, state, or nation, can have but a limited development. The limit is reached when production has so far exceeded the absorbing power of the region that transportation breaks down under the double burden of a seasonal outgoing traffic and an incoming stream of commodities under a demand differently distributed as to time. While Kansas as a state is not limited to a single industry, a very large portion of its area is thus conditioned. Outside of a dozen counties, agriculture is the single important

activity. The greatest benefit that could possibly come to the many agricultural counties would be the creation of thriving centers of industry, with their wage-earning populations building up local home markets and stimulating a more intensive working of the soil.

It is important that the financial and commercial leaders in the state hold a sympathetic and understanding view of such development. It is important that new industries should be of those kinds that have the proper connection with agricultural and other established interests so that they may have the best chances for success; that they are in correct relation to markets; and that they are placed in the most favorable locations with respect to labor, fuel and water supplies. This calls for study and analysis of conditions and of the possible enterprises themselves. It is this that has been attempted in the investigation.

The active supporters whom the author has had the good fortune to find ready to join in the work are the secretaries and committees of the many chambers of commerce, city and county engineers, and members of the Kansas Engineering Society. Railroad officials have also given material assistance in many instances. The heads of many of the existing manufacturing plants have given information freely and have contributed much to the study of those conditions which are fundamental to the success of individual enterprises. Managing officials of the larger electric utilities having extended power-distributing lines have given complete information respecting their properties. Two important state service agencies, namely, the water laboratory of the State Board of Health and the State Geological Survey, have contributed valuable information. Without such support the investigation would have been impossible, and acknowledgment of the assistance rendered is here made.

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PART I.

PRESENT INDUSTRIAL STATUS.

GENERAL CONSIDERATIONS.

THE state of Kansas occupies a position geographically within the United States such that it is destined to exert a more marked influence on industrial relations than it has yet done. It has passed through a series of events in its development that is typical of states in the Mid-West. This has meant great activity in all branches of agriculture, so that Kansas now ranks as one of the foremost food-producing states of the Union. For many years developments in agricultural lines brought rapid growth, but the time has come when the farmers no longer call for increased numbers of workers, and all are familiar with the fact that during the past two decades there has been but a slight increase in population. The general adoption of farm machinery is one of the main factors which has led to this result, but it is not the purpose here to dwell upon the reasons for the flattening of the curve of state growth. Suffice it to say that the various causes which have contributed to this result are entirely normal as pertains to agricultural matters, but in other industrial activities Kansas conditions are not normal. The state is unevenly developed industrially.

As has been stated, Kansas is a great producer of staple food products. Its products along these lines are far beyond the needs of its resident population, while, in turn, the products of general manufactured goods are below the needs of the population. This is no new or unusual condition, since the same statement may be made regarding the majority of states, for some of which one line of products is in excess and for others another line. It is something that is to be expected, but at the same time it indicates a lack of economy in distribution. We are shipping too much freight. For every inhabitant of the country at large there was moved in 1918 more than 25 tons of freight through an average distance of 175 miles. This is a total of 4,400 ton miles per capita, a figure far in excess of that for any other country in the world. During the three preceding years traffic had been increasing by about 10 per cent each year.

Combined with this is the fact that, relative to population, the food-producing power of the country as a whole is diminishing. This is true particularly of those areas which have been devoted to the extensive cultivation of crops on large tracts and ranches. The upbuilding of diversified industries throughout a region like Kansas would mean the bringing of many thousands of people to the source of food supply. It would mean the lessening of the traffic burden, both in the shipment of food products and in the incoming shipment of goods. It would mean the diversification of crops and the stimulation of more intensive methods of agriculture in many scores of communities.

A simple illustration of the effect that would be produced on transportation is afforded by the starch industry. The center of starch production is near the Mississippi river, causing an average haul of about 400 miles to a typical distributing point, like Topeka, within the state of Kansas. By the law of averages, the amount of starch used per capita is about seven pounds per year, which means a shipment of 5,645 tons annually, causing a freight ton-mileage of two and one-fourth million in excess of that which would be necessary were starch manufacturing carried on within the state.* A much more striking illustration is afforded by sugar, the consumption of which is about twenty times as great as starch. The figures are not so readily accessible as to the present center of sugar production, but it is safe to say that with a practicable development of the beet-sugar industry in the west half of the state it would be possible to make a saving of from seven to ten millions of ton miles of freight. While the actual saving of transportation is not the most direct and outstanding reason for industrial development in Kansas, it is one worthy of consideration. The point thus raised brings us face to face with the question as to why there may not be developed a true industrial system for the country as a whole, which would take into account all matters pertaining to economic production and distribution of standard commodities.

Kansas occupies a strategic position with reference to the great markets of the country. It is the center of gravity, and through it flows a stream of commerce to and from the southwest quarter of the country. Kansas City is the natural gateway to this territory. The region inside a wide circle about this city, within the states of Kansas and Missouri, is feeling the influence of this activity. To

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* The recent establishment of the plant of the Corn Products Company in the Kansas City (Mo.) district goes far in changing the situation in respect to this product, but the illustration holds.

fully appreciate what all of this may mean one has but to consider the rapid growth of the southwestern states. The mid-continent oil field lies wholly within the region, and has had and will continue to have a wholesome and stimulating effect upon all forms of progress. This developing field is served by as many as seven class one railroads across the Kansas-Oklahoma line—an indication of the close union between the older producing state of Kansas and the newer territory, wherein as yet little of industry, other than production of raw material, has developed. Four trunk-line railroads connect Kansas to the west across the Colorado line, giving ample connection with the mountain states. Transportation development could not have progressed more consistently if it had been designed with the deliberate purpose to foster the building up of a great producing industry in general manufacturing as well as in foodstuffs in the state of Kansas.

Every medium-sized city of Kansas is in a position such that it should be more directly interested in industrial development. Many of these towns are apparently at the limit of their growth, excepting as new industries are organized. For them industrial development, with consequent diversification of crops in the adjacent districts, is necessary if they are to grow. It is to be borne in mind that the present is the time to formulate plans for an appropriate expansion according to a well-ordered system. City planning is a matter of importance, and it is as easy to develop a town in accordance with correct principles and with a view to health and municipal attractiveness as it is to permit the unauthorized haphazard grouping of activities which tend toward the opposite condition.

PRESENT CONDITIONS.

In several lines of industry at the present time Kansas holds a prominent position among the various states of the country. Most notable among these are meat packing, flour milling, and the concentrating and smelting of zinc. Of recent years zinc smelting has moved in a considerable measure to the gas fields of Oklahoma, but Kansas still retains a considerable amount. Other lines of manufacturing that are of material importance are Portland cement, dairy products, brick and tile, refined salt, glass, foundry and machine-shop products dealing largely with oil-field supplies, and railroad repair shops and car shops. In addition to these there are significant beginnings in such branches as work clothing, cotton gloves, canning and preserving, lumber products, leather goods and tobacco goods.

TABLE I.

	Average number of employees.			Capital (in terms of thousands).			1900.		1910.		1920.	
	1900.	1910.	1920.	1900.	1910.	1920.	Cost of materials.	Value of products.	Cost of materials.	Value of products.	Cost of materials.	Value of products.
Total for State	27,119	44,215	61,049	$59,458	$156,090	$357,534	$120,738	$154,009	$258,884	$325,104	$750,087	$913,667
Meat packing	8,117	10,591	17,805	$16,486	$37,869	....	$67,909	$77,412	$147,646	$165,361	$387,859	$427,663
Flour milling	1,405	2,360	3,493	8,016	22,741	....	18,131	21,329	60,439	68,476	182,333	206,881
Railroad shops	5,592	7,686	11,196	2,932	9,607	....	3,071	6,817	5,219	11,193	10,435	28,231
Zinc smelting	1,487	1,821	717	5,219	9,057	....	4,679	5,790	8,877	10,857	4,664	6,038
Dairy products	395	348	927	1,140	1,776	....	3,062	3,653	4,951	6,071	23,403	27,254
Metal manufacturing	1,276	2,110	2,935	2,484	6,791	....	1,489	2,852	3,034	5,919	6,870	15,023
Cement	....	2,143	1,084	....	16,387	....	....	....	1,556	4,682	3,362	6,700
Brick and tile	905	1,819	1,136	1,755	3,930	....	156	724	531	2,336	1,199	3,407
Salt	450	451	1,072	961	2,544	....	328	717	519	1,106	2,207	6,193
Furniture	220	357	503	243	527	....	142	302	236	616	652	1,365
Candy and confectionery	68	135	584	36	275	....	120	185	172	328	2,393	3,886
Gypsum	....	170	131	....	656	....	....	....	83	287	193	545
Paper and paper goods	....	97	291	....	330	....	....	....	120	218	921	1,779
Glass	....	1,435	584	....	1,769	....	....	....	672	2,037	616	2,133
Agricultural implements	11	126	129	20	563	....	11	18	162	369	453	770
Leather goods	151	339	369	277	1,105	....	205	345	821	1,387	1,930	2,980

In these industries there are employed upwards of 61,000 people. The significance of this is greater than might be supposed. In a direct way manufacturing development is dependent on labor. Older communities have their groups of workers accustomed to factory life, and having close association, group by group, in the various factories and mills. The creation of such a population is a matter of time, and it is of significance to note that already there are many centers in Kansas wherein may be found considerable groups of people accustomed to this class of work. At the same time these groups are, in the main, in the midst of American communities, where the conditions of living and the community atmosphere are conducive to a higher type of citizenship than would be found in the typical manufacturing town of the east. So important is this latter point that many manufacturers have begun to look to the smaller cities in the expectation that the more healthful atmosphere and the higher types of available workers, as to natural characteristics, will more than offset the handicap of lack of association with organized industries. All of this means, in the end, a more wholesome mixture of types, free from the evils peculiar to the more closely segregated workers of the large centers.

It is the avowed purpose of this report to point the way toward methods and conditions which may lead to the upbuilding of industries of various kinds. It is not presumed that there will be immediately a growth such as to produce conditions resembling those found in eastern congested cities. In the very nature of things, it is not to be looked upon as the province of Kansas to manufacture, in great quantities, goods for shipment abroad. The form of development aimed at is one which will serve as a stabilizing and equalizing agency from which a more healthful and progressive form of community enterprise will evolve.

STATISTICS ON MANUFACTURES.

The extent of manufacturing in Kansas is shown in table I, for the total in all lines and also in 16 leading branches. These separate industries are arranged in the order of value of products as indicated in the United States Census report for the year 1910. Because of the extreme fluctuations in values that occurred during the war period, the values of 1920 (in reality the figures for 1919) are of small comparative significance as indications of growth. For purposes of interpreting growth of industries from 1910 to 1920 it is therefore better to use the figures for number of persons employed.

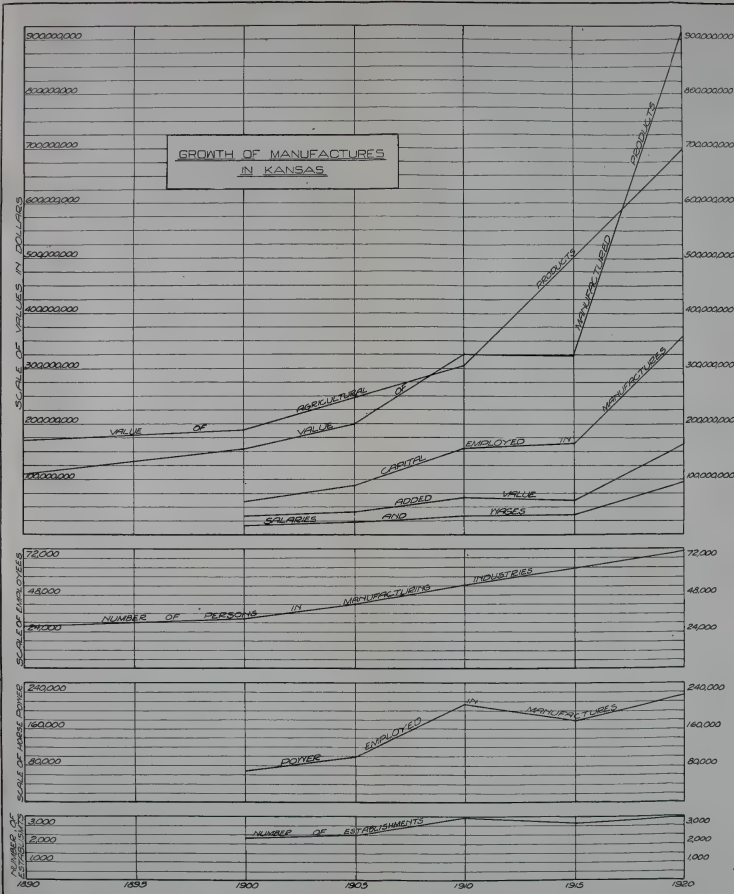

Figure 1.

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On this basis a steady growth for the state as a whole is seen. In many industries the growth is very pronounced, notably in meat packing, flour milling, railroad shops, metal manufactures, and dairy products. In four industries there are decreases. Zinc smelting has been referred to, several establishments having moved into Oklahoma following the depletion of the Kansas gas fields. The decreases in the cement, brick and tile, and gypsum industries are of temporary nature, due in the main to poor marketing conditions in 1919, although the production of gypsum products is likely to remain low for some time.

Figure 1 shows in graphical form the growth of the combined industries of the state over a longer period of years. On this chart are shown curves of value of products, value added by manufacturing, wages paid, capital employed, power utilized, number of persons engaged, and, for comparative purposes, the value of agricultural products. As here represented the agricultural products include farm crops and live stock sold on the market. It is of interest to note that in 1908 the value of manufactured goods became greater than the value of agricultural products, and, after a slight decline in 1914, has risen since to a much larger figure.

The distribution of these industries is a matter of importance. It has been noted already that the building up of an industrial spirit in a community is of prime significance. It means a population accustomed to factory and mill work, in which new industries will thrive, unless unhealthful conditions exist. There are no infected cities in Kansas. Of course there are active labor unions in the larger towns, but the members are American citizens, in large measure, excepting in the more congested packing-house district of Kansas City and the coal fields of Crawford county. These two groups are so distinct, however, that their effects on other industries are not serious. The normal union in Kansas is a sound institution and bespeaks a labor atmosphere in which development may proceed smoothly.

DISTRIBUTION.

Table II shows the distribution of seventeen important industries, on the basis of number of employees. It is inevitable that the number of people employed will vary from month to month, so that in towns where industries are small and few in number, the figures shown may not apply to all localities for any one time. They do represent, however, a fairly representative development for the cities included in the count.

TABLE II.

Cities.	Population.	Persons employed in— Meat packing	Flour milling	Dairy products	Metal manufacturers	Agricultural implements	Railroad shops	Furniture	Cement	Brick and tile	Gypsum	Zinc smelting	Salt	Glass	Leather goods	Paper	Work clothing	Candy
Kansas City	101,177	15,841	714	125	1,160		300										171	3
Wichita	72,217	1,380	305	40	319	69	572	78						18	35		237	163
Topeka	50,022	465	263	304	463		2,800	117		38					53		7	43
Hutchinson	23,298	60	326		40								450			180	20	95
Pittsburg	18,052	49	25	7	464	4	858			307					7			66
Leavenworth	16,912	50	110	13	481	23		340							25		196	30
Parsons	16,028	15	14	100	387		2,400										40	
Salina	15,085	30	301	28	20	60									3			65
Coffeyville	13,452		125	9	373					266		145		9		30		
Atchison	12,630		305	11	584	105									173		47	25
Lawrence	12,456		67	8	10			15		50					5	225	40	
Independence	11,920			6	65				378	70								10
Emporia	11,273		16	12	14													18
Arkansas City	11,253	80	140		20		758										80	40
El Dorado	10,995																	
Fort Scott	10,693		25	73			450		50	55					34		81	2
Chanute	10,286			12	118		650		300	50								
Newton	9,781		120	14			215										46	
Ottawa	9,018		45		20	2	500											
Iola	8,513				200				300			300					100	200
Manhattan	7,989																	
Winfield	7,933		70	51	22													8
Junction City	7,533		20				250											
Wellington	7,048		156				300											
Pratt	5,183		35	6			100											

Dodge City	5,061		30	14														
Abilene	4,895		108	50														
Galena	4,712																	
Concordia	4,705		20	25	5													10
Cherryvale	4,698		40	6	46					115		403						
McPherson	4,595		44	20	5													
Great Bend	4,460		151	25	6													2
Augusta	4,219				180									250				
Herington	4,065						650											
Horton	4,009						675											
Fredonia	3,954		7						100	135				275				
Neodesha	3,943			4	6													
Garden City	3,848																	
Clay Center	3,715		30	60	4													
Caney	3,427				18													
Olathe	3,268			6											85			
Paola	3,238		5							17								
Hiawatha	3,222		5	4	7													
Hays	3,165		50															
Girard	3,161		25	2	15													2
Larned	3,139		20	3	38										30			
Osawatomie*	3,085						150											
Marysville	3,048		23	3			500											8
Council Grove	2,857		5	40			40											
Yates Center	2,800						125	8										
Anthony	2,740		20	4									47		9			
Belleville	2,710		6	5			200											
Holton	2,703			20														2
Humboldt	2,525								200	40								
Lyons	2,516		55										170					
Marion	2,500	28		5														
Oswego	2,407		15															
Caldwell	2,387		50															
Kingman	2,381		45	15														
Norton	2,237		11	6		10												
Garnett	2,158			14				40		15								
Seneca	2,100									15								
Ellis	2,039						270											
Sterling	1,982		3										15					
Minneapolis	1,923		12															

TABLE II—CONCLUDED.

Cities.	Population.	Persons employed in— Meat packing	Flour milling	Dairy products	Metal manufacturers	Agricultural implements	Railroad shops	Furniture	Cement	Brick and tile	Gypsum	Zinc smelting	Salt	Glass	Leather goods	Paper	Work clothing	Candy
Lindsborg	1,812	......	39	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Russell	1,790	......	15	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Stafford	1,657	......	32	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Harper	1,547	......	25	3	......	......	......	......	......	......	......	......	......	......	......	......	......	......
St. John	1,540	......	37	......	2	......	......	......	......	......	......	......	......	......	......	......	......	......
Wamego	1,540	......	15	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Bonner Springs	1,484	......	......	......	......	......	......	......	206	......	......	......	......	......	......	......	......	......
Pleasanton	1,333	......	15	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Medicine Lodge	1,322	......	7	......	......	......	......	......	......	......	90	......	......	......	......	......	......	......
Halstead	1,174	......	26	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Mulvane	1,163	......	......	60	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Clyde	1,145	......	25	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Howard	1,137	......	25	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Ellinwood	1,097	......	35	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Enterprise	......	......	60	......	55	......	......	......	......	......	......	......	......	......	......	......	......	......
Buffalo	......	......	......	......	......	......	......	......	......	70	......	......	......	......	......	......	......	......
Buffville	......	......	......	......	......	......	......	......	......	125	......	......	......	......	......	......	......	......
Mildred	......	......	......	......	......	......	......	......	200	......	......	......	......	......	......	......	......	......

The industry having the most general distribution is that of flour milling. Of the 82 towns included in table II all excepting 25 have at least one flour mill doing regular business. Next to this in matter of distribution are the dairy-products business, with plants in 40 towns, and metal manufactures in 32 towns. Closely associated with the latter are the agricultural-implement plants and railroad shops, which increase to 44 the number of towns in which substantial business in metal working is carried on. The general group employed in machine-working lines is of particular significance, because it represents a type of labor that is especially promising and favorable to the development of a higher class of working population.

Brick and tile are manufactured in 15 cities located in 11 counties. There are many more brick plants than are shown here, located in very small towns in these and several other counties. These and other industries based on the clay and shale deposits of the state are commented upon especially in Part IV.

An industry not mentioned in the list, but which furnishes a good illustration of concentration due to personal activity, is that of cigar manufacturing. The small city of Marysville produces a large proportion of the cigars made in the state, sharing on practically even terms with Topeka in extent of business, each employing 65 to 70 persons. There are a few other scattered plants in the state, generally small.

The industry employing the largest number of people in the state is that of slaughtering and meat packing. It is concentrated mainly in Kansas City, with substantial developments in Wichita and Topeka. Because of this congestion it does not exert so great an influence on the industrial population. It is a notable industry, however, producing goods which make up a very large portion of the total value of products. The number of people employed is not nearly as large as the proportion of value of products would seem to indicate. Causes leading to this are discussed in more detail in Part III.

FACTORS AFFECTING FUTURE DISTRIBUTION.

Treating in a broad and general way the question of distribution of industry in the state, viewing future possibilities more particularly than present development, it is evident that three factors will exert a marked influence on the locations of significant enterprises. The first of these applies only to industries which are based on raw materials which must be employed near their point of origin.

TABLE III.—WATER SUPPLIES OF KANSAS.

CITY.	Analysis—grains per gallon.							Source.	Treatment.	Present maximum demand, gallons per day.	Maximum capacity of plant, gallons per day.
	CA.	MG.	HCO_3.	SO_4.	Iron.	Sulphur.	Total solids.				
Kansas City*	4.8	1.3	10.8	6.1			26.0	Missouri river	Sed., Coag., Filt	23,400,000	15 to 24 mil.
Wichita	8.7	1.7	13.7	17.5	0.04		100.0	Shallow wells		8,600,000	19,000,000
Topeka*	2.6	0.55	5.8	5.3	0.00		18.0	Kansas river	Sed., Soft., Coag., Filt	4,500,000	8,000,000
Hutchinson	8.0	1.35	14.5	9.6	0.70		65.0	Shallow wells		6,000,000	8,000,000
Leavenworth*	4.0	1.7	10.7	7.2			26.0	Missouri river	Sed., Coag	3,910,400	12,000,000
Pittsburg	3.7	1.7	18.4	4.8	0.004	+		Deep wells		1,700,000	4,150,000
Parsons*	5.3	1.4	13.2	10.0	0.06	—	37.0	Neosho river	Sed., Coag., Filt	4,000,000	6,000,000
Parsons*	1.8	0.43	3.7	2.5	0.04	—	17.0	Labette creek			
Coffeyville*	5.6	0.91	17.5	3.7			24.5	Verdigris river	Sed., Coag., Filt	3,500,000	4,000,000
Salina	9.7	2.0	30.0	10.0	0.06		46.0	Shallow wells		2,000,000	2,500,000
Atchison*	4.0	1.7	10.7	7.2			26.0	Missouri river	Sed., Coag	2,000,000	2,225,000
Lawrence*	2.6	0.55	5.8	5.3			18.0	Kansas river	Sed., Soft., Coag., Filt	1,500,000	3,000,000
Fort Scott*	5.6	0.49	15.6	3.3			15.6	Marmaton river	Sed	2,100,000	3,000,000
Independence*	2.8	0.35	8.0	3.0			17.5	Verdigris river	Sed., Coag., Filt	2,500,000	3,000,000
Arkansas City	6.3	1.30	13.0	10.0	Trace		64.0	Shallow wells		3,000,000	4,000,000
Emporia*	4.7	0.82	15.5	2.9			18.0	Neosho river	Sed., Coag., Filt	1,800,000	3,000,000
El Dorado*	4.8	0.64	17.0	5.5			18.0	Walnut riv. shal. wells	Sed., Coag., Filt	900,000	1,000,000
Chanute*	5.0	0.46	12.0	5.2			17.5	Neosho river	Sed. Coag., Filt	921,600	3,000,000
Newton	3.0	0.49	15.0	1.5	0.11		16.0	Shallow wells		2,369,304	5,500,000
Ottawa*	4.7	0.80	11.0	5.5			16.0	Marais des Cygnes river	Sed., Coag., Filt		2,500,000
Iola*	4.9	1.00	10.6	7.2			17.5	Neosho river	Sed., Coag	2,225,000	3,000,000
Winfield	2.96	0.99	22.4	1.7	0.04		21.8	Shallow wells		2,000,000	5,000,000
Manhattan†	7.3	1.3	27.0	3.6	0.27		35.0	Shallow wells		1,100,000	3,000,000
Wellington	3.3	1.05	15.5	1.8	0.00		21.0	Shallow wells		800,000	1,000,000
Junction City	4.4	0.94	17.0	2.8	0.07		30.0	Shallow wells		1,500,000	2,000,000
Herington	4.2	2.1	17.5	5.0		—	25.0	Spring		400,000	500,000
Abilene	2.6	0.55	9.1	1.4	0.03		14.0	Sand spring		1,000,000	1,500,000
Great Bend	6.0	1.17	11.0	15.0			41.0	Shallow wells		1,000,000	2,500,000
Concordia	5.6	1.0	22.0	4.3	0.007		32.0	Shallow wells		900,000	2,000,000
Cherryvale*	3.4	0.55	10.5	2.0			16.6	Verdigris river	Sed., Coag., Filt	500,000	1,500,000
McPherson	5.8	0.61	17.5	1.6	.15		24.0	Shallow wells		500,000	900,000

Clay Center	13.8	2.35	21.4	29.3	1.87		69.0	Shallow wells		300,000	
Neodesha*	3.8	0.82	14.0	1.7	0.03		16.6	Fall river	Sed., Coag., Filt	750,000	3,000,000
Horton*	2.67	0.8	10.8	3.0			16.0	Impounding reservoir	Sed., Coag,. Filt	80,000	500,000
Fredonia*	3.8	0.82	14.0	1.7	0.03		16.6	Fall river	Sed., Coag., Filt	350,000	1,000,000
Olathe*	3.8	0.5	7.9	4.4			16.0	Cedar creek	Sed., Coag., Filt	245,000	500,000
Caney*	3.1	0.35	5.7	0.72			17.0	Caney river	Sed., Coag., Filt	300,000	1,000,000
Marysville*	4.3	0.88	15.8	4.5			24.0	Blue river	Sed., Coag., Filt	250,000	675,000
Beloit*	5.4	0.94	17.0	8.3			31.0	Solomon river	Sed., Coag., Filt	600,000	750,000
Paola*	5.1	0.57	13.5	4.0			20.0	Bull creek	Sed., Coag , Filt	500,000	1,600,000
Columbus	2.9	1.4	22.0	3.9	0.03	Present	29.0	Deep wells		327,000	864,000
Hiawatha	3.9	1.0	19.5	0.53	Trace		17.0	Wells and springs		300,000	300,000
Lyons	6.5	0.8	18.0	2.0	0.03		36.0	Shallow wells		600,000	864,000
Council Grove*	4.7	0.82	15.5	2.9			18.0	Neosho river	Sed., Coag., Filt	350,000	720,000
Holton	4.9	2.1	21.0	1.95			23.0	Shallow wells		120,000	125,000
Yates Center‡											
Eureka*	4.6	0.82	17.0	1.9			21.0	Fall river	Sed., Coag., Filt	320,000	500,000
Belleville	0.4	0.24	28.0	10.6	0.13		83.0	Shallow wells	Lime Treat., Sed. or deferization,	175,000	190,000
Garnett*	4.2	0.4	10.8	3.6			15.5	Cedar creek	Sed., Coag., Filt	400,000	552,000
Marion‡											
Seneca	4.4	1.3	22.0	2.3	0.05		21.0	Shallow wells, springs		120,000	
Sabetha	6.0	3.0	22.0	10.8	0.07		40.0	Shallow wells		60,000	130,000
Minneapolis	4.2	0.91	16.0	3.2	0.09		26.0	Shallow wells		30,000	144,000
Cottonwood Falls	7.2	1.8	30.0	2.7	0.22		32.0	Shallow wells		15,000	90,000
Washington*	3.6	0.55	10.7	2.9			17.0	Mill creek	Sed., Coag., Filt	125,000	576,000
Elk City*	5.2	1.0	15.5	3.2			17.0	Elk river	Sed., Coag., Filt	30,000	216,000

* Surface water supply. Chemical condition varies considerably with rainfall and variation in stream flow. Mean values taken from records in Water and Sewage Laboratory with free use of Water Supply Paper 273, U. S. G. S.

† Building softening plant.

‡ Supply not supposed to be used for domestic purposes. Quality bad.

This is obvious and needs no discussion. The second is that of transportation, and this again is a matter so well understood that discussion is unnecessary.

WATER SUPPLY.

But the third great influence, and the one which will become a most significant factor when the industrial life of the state has reached really large proportions, is that of water supply. The grouping along the valleys of the larger rivers is already apparent. The towns in the Missouri river and Kansas river valleys will have a marked advantage by reason of the fact that at all times of the year there is a flow of water sufficient to insure steady supply to meet all demands that are likely to come. There are several other rivers in the state which will meet the demands for some time, until development reaches a magnitude several times that which now exists, but in all of them the limit will be reached ultimately. There is little doubt but that water will set the limit for development in many of the cities. In view of this it is particularly important that more concrete investigation should be made concerning the extent and availability of the underground waters. Over a large portion of the west and south-central sections, ground water is being employed already in a variety of ways, for irrigation and steam power purposes as well as for domestic supply. This water is a most important asset, the full value of which is not realized at the present time. The time will come when it will be seen that the growth and development of the cities will hinge on the available supply of this natural resource.

The above statement has been made with reference to quantity. The quality of the water supply is another matter, the importance of which needs no argument. Certain industries are peculiarly dependent upon it, such matters as the appearance of sulphur having to do with the possibility of using the water in certain manufacturing processes. Table III gives a fairly complete list of the water supplies of the state. The usual chemical analysis is given, together with statements as to the character of treatment now being administered.

The accompanying map (Figure 2) shows the locations of the 82 towns included in this table of distribution of industries. Their association with the rivers of the state, and also with the lines of the main trunk railroads, becomes clearly apparent.

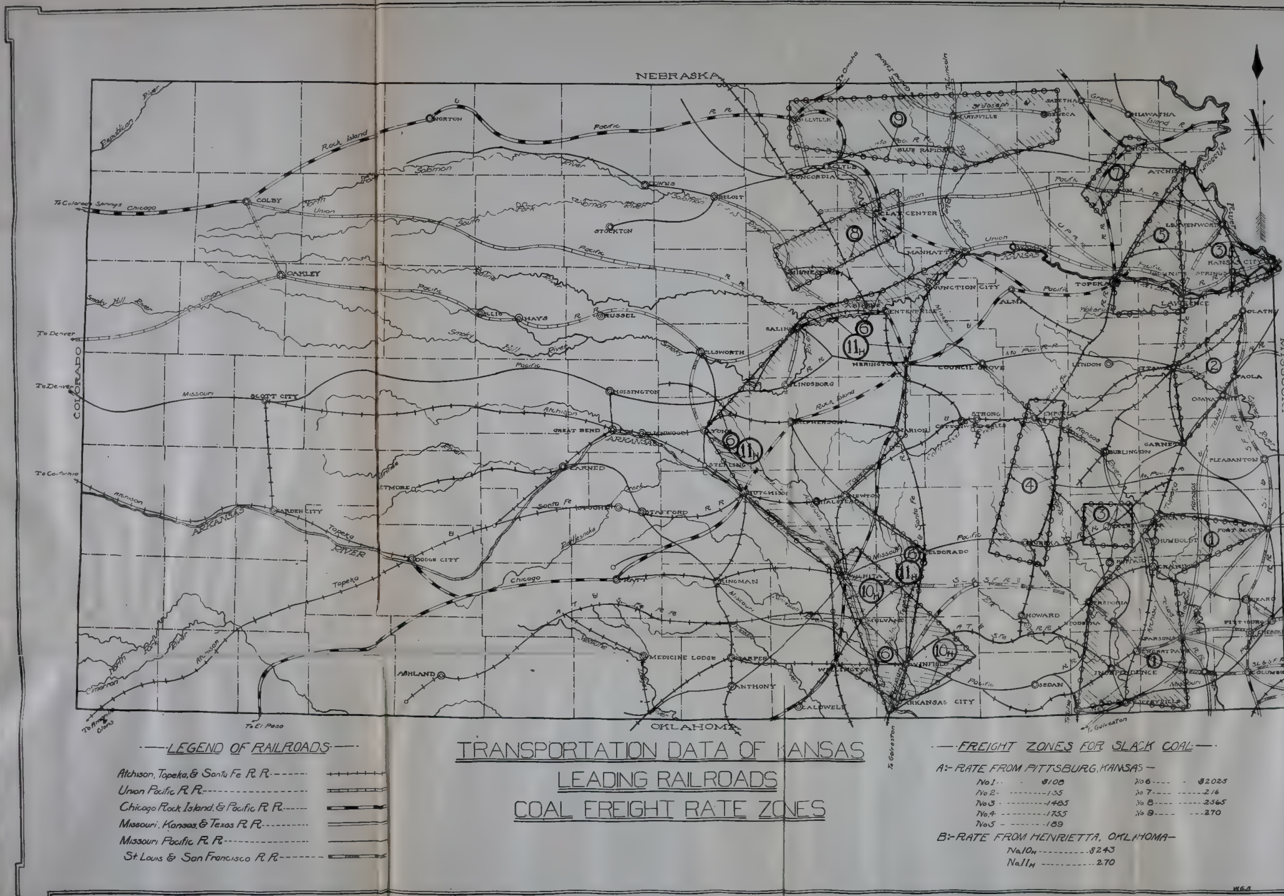

Figure 2.

9-4186

PART II.

GENERAL INDUSTRIAL AND ECONOMIC DATA.

A NECESSARY preliminary to activities having as their object the building up of industries is a careful scrutiny of the economic and commercial conditions existing in the various sections of the state. If new enterprises are to be located in accordance with a sound policy that will take into account all of the conditions vital to success, such facts as are significant must be known and studied with care. The most vital influence in this whole region is that of the market, and the agencies which are influencing the upbuilding of that market. The maintaining of financial strength and the means for transportation which determine the possibilities for quick and economic delivery of goods, also are matters of most vital concern. There are also several facts to be noted concerning the supply and character of labor, the conditions affecting wages, and rates charged in the community for electric power and for water for both domestic consumption and for large users.

In Table IV there is shown information touching these matters. The towns covered by the tabulation include most of the county-seat towns having a population of 2,000 and over, and several other cities which already have a significant industrial development. There are several towns in this list which have notable developments in certain important industries, some of which have been referred to in Table II, wherein the distribution of these industries was being considered. It has been impracticable with the means at hand to attempt to cover every town in full detail, even though it is recognized that certain of them which have important single industries might easily attract certain other industries to their immediate neighborhood. Most of the representative towns of this state are included in Table III, however, and the information given may be taken as representative of conditions in the communities represented.

GRAPHICAL CHART.

Some of the more significant relationships between the various quantities shown in this table are presented in graphical form on Figure 3. These ratios are: Industrial employees per 1,000 population; men to women employees; bank capital and surplus per indus-

trial employee; assessed valuation per capita; power rate, cents per kw. hour (basis 25,000 kw. hours per month); water rate, cents per 1,000 gallons (basis 10,000,000 gallons per month). These ratios have been taken in such manner that the small city may appear on an equal footing with the larger city, in accordance as conditions may have developed. It is frequently true that a moderate-size town presents opportunities in fully as favorable a manner as does the large city, provided it has the actual volume of labor necessary to maintain stable conditions. Those interested in conditions in their own communities will do well to study the facts revealed in this diagram.

Regarding the first item at the top of the chart, the actual number of people employed in organized industries may be taken as an index of the extent to which the town has become accustomed to this type of enterprise. There is an exception to this statement, however, especially when the employees in very large proportion are in a single industry. There are several instances of towns where railroad shops of considerable size have been located and very few other activities. When such is the case the development represented is bound to be somewhat abnormal. A comparison of the information given in Table II with that in Table III will reveal the cases where this is most pronounced. Care should be used not to construe too literally in the cases of cities which appear to employ but a limited number of people. Since the persons engaged in mercantile pursuits are not included, cities like Wichita and Salina, which have a very extensive wholesale business, show somewhat to a disadvantage. In these towns there are, as a matter of fact, many persons in addition to those represented on this diagram who are connected with organized activities. Such towns have the further advantage of having well-developed marketing systems.

In the second portion of this figure there is shown the ratio of men to women employed. This information is of considerable importance, as it may serve to indicate in some measure the type of industry which the town is in a condition to support. It seems clear that where many men are employed in proportion to women there is a likelihood that there are women who desire employment. There may be modifying factors in any community, however, so that too great stress should not be laid upon this. It serves as a general indication, but other conditions must be known. When such ratios occur as are seen in the cities of Pittsburg, Atchison and Coffeyville, there is every reason to believe that such conclusion as that just in-

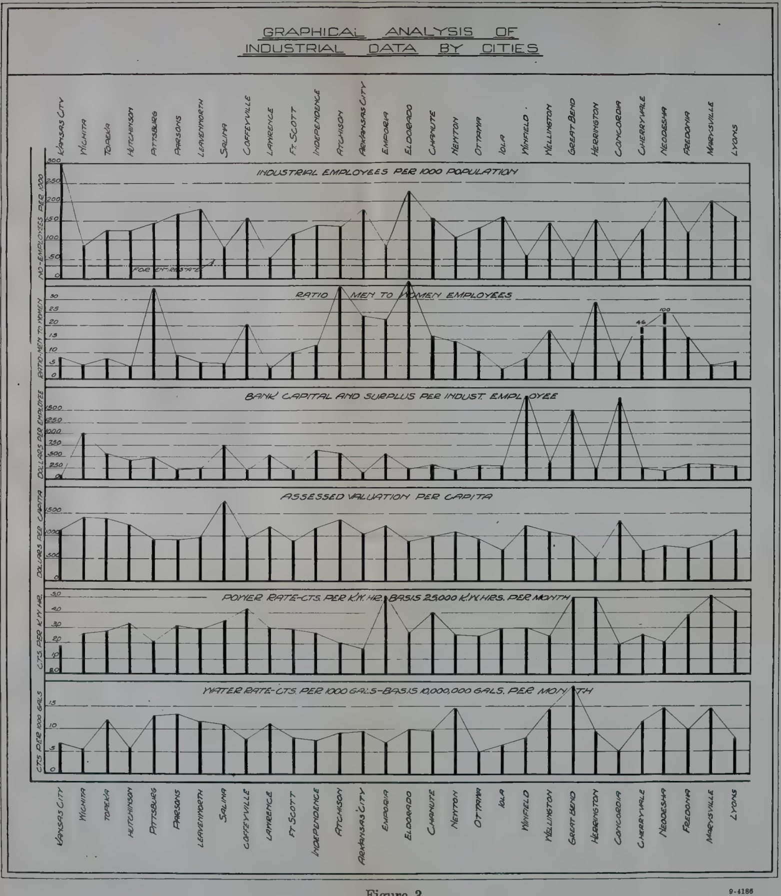

Figure 3.

9-4186

TABLE IV.—GENERAL INDUSTRIAL DATA.

Cities.	Population.	Assessed valuation.	Tax rate.	Banks, capital and surplus.	Industrial employees. Men.	Industrial employees. Women.	Industrial employees. Total.	Industrial employees per 1,000 population.	Ratio of men to women employees.	Bank surplus and capital per industrial employee.	Power rate, based on monthly consumption of 25,000 Kw. hours. Cts. per Kw. hour.	Power rate, based on monthly consumption of 25,000 Kw. hours. Monthly bill.	Electric light rate, residences. Cents per Kw. hour.	Water rate, residences. Cents per 1,000 gallons.	Water rate based on monthly consumption of 10,000,000 gallons. Cents per 1,000 gallons.	Freight rates June, 1922, on coal from— Southern Kansas field, Pittsburg. Lump.	Southern Kansas field, Pittsburg. Slack.	Oklahoma field, Henryetta. Lump.	Oklahoma field, Henryetta. Slack.
Kansas City	101,177	$112,427,600	21.30	$2,575,000	26,468	3,407	29,875	295.0	7.76	[illegible]	1.85	$462.50	6	25	6.71	$1.89	$1.485	$3.64	$2.565
Wichita	72,217	103,461,213	23.10	6,389,105	5,342	986	6,328	87.8	5.41	1,009	2.64	656.12	7½	25	5.54	2.43	2.025	2.835	2.43
Topeka	50,022	68,537,950	21.56	3,500,000	5,497	739	6,236	124.6	7.41	637	2.78	...	...	45	12.17	2.295	1.89	4.185	2.70
Hutchinson	23,298	28,836,342	23.30	1,170,000	2,311	555	2,866	123.0	4.2	408	3.30	825.00	5.75	30	5.50	2.835	2.025	3.645	...
Pittsburg	18,052	16,741,115	25.55	993,000	2,500	71	2,571	142.3	35.2	373	2.08	520.00	8.5	25	13.32	...	...	2.97	...
Leavenworth	16,912	16,434,160	24.50	700,000	2,600	400	3,000	177.4	6.5	233	2.84	709.50	11	...	11.68	2.16	2 025	3.915	3 375
Parsons	16,028	15,349,100	22.88	601,300	2,402	282	2,684	167.5	8.5	224	3.17	793 00	10	40	13.50	1.215	1.08	2 565	2.295
Salina	15,085	26,350,234	17.90	878,189	1,034	162	1,196	79.3	6.3	734	3.42	855.00	12	30	10.14	2 835	2.025	3.645	2.70
Coffeyville	13,452	12,582,797	26.725	390,000	2,018	95	2,113	156.5	21.1	184	4.22	1,055.00	12	30	7.86	1.62	1 08	2.70	2.295
Atchison	12,630	16,993,399	21.00	985,000	1,623	44	1,667	131.9	36.9	591	2 00	500 00	10	35	9.57	2.025	1.755	3 915	3.375
Lawrence	12,456	15,912,352	21.71	1,023,000	538	131	669	49.7	4.1	1,529	3 00	750 00	10	45	11.25	2.16	1.89	3.915	...
Independence	11,920	14,168,074	24.77	1,072,000	1,616	128	1,744	145.3	12.65	615	2.67	667.00	8.5	30	7.63	1.62	1.08	2.565	...
Emporia	11,273	14,257,848	18 00	550,000	912	39	951	80 6	23.35	578	5.08	1,268.00	10	30	7.38	2.16	1.755	3.51	2.835
Arkansas City	11,253	11,997,252	30.90	250,000	1,983	83	2,066	178.7	23.9	121	1.63	406 50	8.5	25	10.0	2.43	2.025	2.835	2.43
El Dorado	10,995	9,787,900	32.30	550,000	2,518	60	2,578	228.9	42.0	218	2.67	667.00	9	30	10.10	2.43	2.025	2.835	...
Fort Scott	10,693	9,224,873	28.175	250,000	1,153	109	1,262	118.0	10.5	572	2.90	506.30	15	27.5	8.45	1.215	1.08	2 835	2.43
Chanute	10,286	10,081,325	21.50	563,500	1,483	92	1,575	153.0	16.1	351	4.00	1,000.00	8	25	10.0	1.485	1.08	2.835	2.43
Newton	9,781	10,576,298	21.20	220,000	978	68	1,046	106 8	14.35	210	2 59	647 00	7.5	33⅓	14.72	2.70	2.025	3 645	...
Ottawa	9,018	8,886,975	22.80	370,500	1,161	105	1,266	132.6	11.1	292	2.50	625.00	7	33⅓	5.0	1.62	1.35	2.70	...
Iola	8,513	5,727,145	26.80	350,600	1,042	348	1,390	163.2	2.99	252	3.00	750.00	5	26⅔	6.56	1.485	1.08	2.97	2.43
Manhattan	7,989	8,809,520	22.40	350,000	137	35	172	21.5	3.9	2,070	2.20	550.00	12	20	7.47	2 565	2.025	4.32	2.97
Winfield	7,933	9,741,690	25.75	857,000	415	50	465	58.2	8.3	1,842	3.06	765 00	10	25	8.30	2.43	2.025	2.835	2.43
Junction City	7,533	7,961,323	28.00	545,000	102	26	128	17.0	3.9	4,258	3.08	769.00	10	25	8.0	2.70	2.025	3.51	2.97
Wellington	7,048	7,659,050	25.90	360,000	980	51	1,031	146.3	19.2	349	2.50	625 00	8	20	15.05	2.43	2.025	3.24	2.70
Abilene	4,895	6,104,857	23.20	410,000	168	18	186	37.2	9.3	2,203	5.00	1,250.00	10	25	5.08	2.835	2.025	3.645	2.70
Concordia	4,705	6,305,419	18.90	395,000	199	26	225	47 3	7.7	1,755	1.97	492 50	13	Flat	5 33	3.375	2.295	5.265	...
Cherryvale	4,698	3,214,203	30.475	130,000	593	13	606	128.9	45.6	214	2 59	647 00	7.5	50	12.0	1.485	1.08	2.16	...
McPherson	4,595	6,406,633	17.52	200,000	155	10	165	35.9	15.5	1,210	3.00	750.00	10	25	8.07	2.835	2.025	3.645	2.70
Great Bend	4,460	5,973,290	24.38	490,000	275	45	320	53.3	6.1	1,531	5.00	1,250.00	10	37.5	20.0	3.51	2.43	4.455	...
Herington	4,065	2,715,311	31.00	187,500	776	26	802	154.2	29.8	234	5.00	1,250.00	14	20	10.01	2.70	2.025	3.645	2.70
Horton	4,009	2,656,540	29.60	...	730	11	741	151.3	66.3	...	5.02	1,256.13	15	75	40.05	2.565	2.16	4.455	...
Fredonia	3,954	2,937,480	35.00	202,500	618	22	640	161.8	28.1	316	3 80	950.00	10	Flat	10.0	1.89	1.08	2.295	...
Neodesha	3,943	3,170,875	27.50	150,000	860	8	868	211.1	107.5	173	2.02	504.00	10	15	15.0	1.62	1.08	2.16	...
Clay Center	3,715	5,163,144	17.90	555,000	150	...	150	39.5	...	3,700	2.77	692.50	10	25	8.0	3.105	2.565	4.995	3.24
Caney	3,427	2,391,094	35.37	125,000	493	7	500	145.9	70.3	250	3.02	754.20	14	50	6.35	1.89	1.08	2.565	...
Beloit	3,315	4,601,493	28.875	325,000	45	6	51	15.9	7.5	6,375	5.24	1,310.00	14	40	15.27	3.645	3.375	5.94	...
Olathe	3,268	3,627,345	30.50	...	...	...	...	...	...	...	3.04	758.00	5	50.5	23.99	1.62	1.35	2.97	2.43
Paola	3,238	4,485,223	20.90	462,000	76	7	83	25.1	10.8	5,568	4 81	1,203.60	12	Flat	15.0	1.485	1.35	2.97	2.43
Hiawatha	3,222	3,709,600	25.00	310,000	51	...	51	17.0	...	6,373	2.62	655.00	11	40	Special	2.70	2.295	4.455	...
Hays	3,165	...	...	230,000	131	12	143	41.0	10.9	...	4.00	1,052.50	...	...	...	3.78	3.51	5.40	...
Columbus	3,155	2,595,193	25.12	250,000	...	...	...	...	...	...	5.60	1,400 00	12.5	40	Special	1.08	1.00	2.295	...
Marysville	3,048	3,003,613	25.50	230,000	597	110	707	207.5	5.4	325	5.01	1,251.50	14	30	15.0	2.97	2.70	4.995	...
Council Grove	2,857	2,320,217	32.00	320,000	138	30	168	58.0	4.6	1,904	4.00	1,000 00	12	30	12.50	1.755	1.35	3.78	2.835
Yates Center	2,800	1,964,432	24.20	104,500	50	8	58	20.7	6.25	1,802	3.06	765.00	10	30	30.0	1.89	1.485	2.565	...
Belleville	2,710	2,656,090	25.33	105,000	238	14	252	93.0	17 0	417	2.50	625.00	12	Flat	40.0	3.24	2.70	5.67	4.86
Holton	2,703	3,659,924	21.30	175,000	92	36	128	47.4	2.5	1,367	6.56	1,634.00	15	100	16.06	2.43	2.16	4.185	3.24
Anthony	2,700	...	...	240,000	121	28	149	55.2	4.3	1,610	...	...	...	...	...	...	...	...	...
Eureka	2,606	2,892,989	31.60	325,000	36	9	45	16.7	4.0	7,220	6 01	1,501.20	13	35	10.0	2.16	1.755	2.70	...
Lyons	2,516	3,369,829	23.50	135,000	450	60	510	171.1	7.6	265	4.03	1,007.00	11	25	8.0	2.97	2.025	4.05	2.70
Marion	2,500	2,145,982	23.80	140,000	55	...	55	22.0	...	2,546	4.00	1,000.00	10	20	10.01	2.70	2.025	3.51	2.835
Garnett	2,158	2,322,045	25.40	70,000	140	...	140	65.0	...	500	4.01	1,003.75	10	75	16.0	1.485	1.35	2.565	...
Seneca	2,100	2,368,062	29.00	311,400	52	[illegible]	61	29 0	6.0	5,107	4.66	1,165.50	12	30	12.91	2.97	2.70	4.80	...
Sabetha	2,030	2,463,080	24.20	245,000	40	...	40	19.7	...	6,128	4.00	1,000.00	12	40	20.05	2.835	2.565	4.725	...
Minneapolis	1,923	2,668,629	18.25	225,000	27	1	28	14.6	27.0	8,040	5.00	1,250.00	12.5	40	10.11	3.105	2.565	4.725	...

dicated may be safely drawn. Finer distinctions may not be made with certainty, however, as is illustrated by the situation in Independence. The relatively high figure shown for that city indicates a comparatively small number of opportunities for women to find employment. As a matter of fact, Independence has several large business offices which give employment to women in large numbers, which fact serves to modify conditions apparently shown by the diagram. The notable low ratios for towns like Hutchinson, Lawrence and Iola show conclusively, on the other hand, that in these towns there should be a building up of general industries which employ men. It so happens in each of these towns that there is a varied group of industries, for which general conclusions as represented by this ratio will apply.

The question may be asked as to what is the proper and normal ratio between men and women employed in organized industry. It is doubtful, however, if a satisfactory answer can be given. Cities are bound to differ in this regard, so that it would not be safe to assume that labor of the desired kind could be found up to the limit set by such a standard figure. Conditions which influence in this are such matters as nationality of workers, the character of industries employing men in large numbers, with special reference to the scale of wages paid, and the general wealth of the community. It is noticeable that our most representative industrial cities, Kansas City, Wichita, Topeka and Leavenworth, have ratios varying from 5 to 7.5. It is probable that the normal ratio is somewhere within these limits, excepting as rather special standards might tend to interfere with the rule. Marked variations from this, such as those noted at Pittsburg and Atchison in the high levels and Lawrence and Iola for the lower, are fairly reliable indications that industries employing the one sex or the other may find favorable opportunities for development.

The third portion of the figure, showing the amount of combined capital and surplus of banks in proportion to the number of industrial employees, is an interesting one. Attention is drawn to the two largest cities, which represent notable extremes. Kansas City is in a peculiar situation. It has a very large industrial population, but a small banking business, the latter being true because of the great financial influence exerted by the banking institutions of Kansas City, Mo. Wichita, on the other hand, has a large mercantile wholesale business as well as being the center of a rich agricultural district, and also has developed in recent years a considerable interest

in oil production. These conditions tend toward the creation of a large banking business. The same thing can be said regarding Salina and Independence, which are the other towns showing high points on this line among the larger cities. It is interesting further to note the high points reached by such smaller county-seat towns as Winfield, Great Bend and Concordia. These three towns are at the centers of important agricultural districts, which interests have led to the building up of the banks. It is not to be concluded, therefore, that because a city is the seat of a large banking business as measured on this scale it is ready to give notable financial support to industrial undertakings. It has a certain significance, however, in that it does represent considerable loaning ability on the part of those institutions toward which the manufacturer looks in times of stress.

The line showing assessed valuation per capita shows less fluctuation than does any other in the figure. Salina is the town of greatest wealth, while Herington, a notable railroad point, occupies the other extreme position. The significance of valuation is general in character, the figure serving only as a general indication of the financial strength of the community.

The line indicating the rates charged for electric power affords some interesting variations. The towns conspicuous for low rates are Kansas City and Arkansas City. In the first we have a notable illustration of a municipally owned plant which has been brought to a high degree of effectiveness. In the latter we have an illustration of a progressive privately owned plant enjoying the advantage in that city of having a water-power development which has been enabled to set a rate below those charged in other cities supplied by the same company. Coffeyville, Emporia and Chanute are towns in which the rates are notably high. The rates in all cases are figured on the basis of a company having a connected load of 150 horsepower and using current at the rate of 25,000 kilowatt hours per month. This represents a power demand of a moderate-size industrial establishment large enough to secure essentially the minimum rate.

No special comment is necessary regarding the rate charged for water, information regarding which is given in the lower section of the diagram. Among the larger cities, Topeka shows a rate that is relatively high. A new plant was under construction at the time when this data was gathered, so that the figure given may not apply in the future when conditions have settled to more nearly normal basis. It is natural that the rates for both water and electric power should tend to become higher for the smaller cities.

PART III.

INDUSTRIES THAT ARE DESIRABLE FOR KANSAS.

IT GOES without saying that industries to be desirable must be successful. In discussing possibilities for Kansas, therefore, the first consideration must be those conditions that are fundamental to success. It is essentially a matter of plant location. No city wishes to bring a factory to town unless it can have a fair assurance that conditions are right for continuous operation for an indefinite period.

MARKETS.

The first consideration is the market. Goods are produced to be sold, and the demand as to quantity and quality in the sales region must determine conditions of manufacture. The large and well-organized concern that is looking for a location for a branch plant, or that is considering an actual change in location, has this matter well in hand. But the new company that has been organized for some special enterprise needs careful watching. No market, local or foreign, may be taken for granted without a complete study of needs and a careful laying out of the plan for conducting sales. Kansas itself is a market for many products that would keep busy several fair-sized plants, but no one of these could expect to secure all of the trade. Take agricultural implements as an illustration. Many varieties of each general class of implement are on the market. A new design must fight for its share of the trade, contending against established trade-connection advantages of its rivals, and also against an unexplained but very real tendency for purchasers to assume that an article manufactured at a distant point is better than the article produced locally. Strange as it may seem, this tendency is characteristic of people in Kansas and calls for some serious study and campaigning.

The result of these influences is that a prospective manufacturer must include a larger territory in his planning. This is easily done here, since the adjoining states of Oklahoma, Colorado, Nebraska, north Texas, western Arkansas and New Mexico are within the natural marketing region reached from the Kansas City district. This gives quite a different aspect to the matter, not alone in agri-

cultural implement lines but in a very large number of lines of manufactured goods as well. It is the most promising territory in the country at this time, when considered from the standpoint of new marketing regions. The population growth has been most marked. The railroad service has been developed as a means of caring for outgoing raw materials in the main, together with the usual ingoing package freight. The opportunity is ready and waiting as the country as a whole revives from the general business depression of the past two years. In any one of a dozen or more towns in eastern and south-central Kansas it will be feasible to organize such enterprises, provided the other attendant requirements are met in a way to insure effective production. Nature, through the river systems, has established the great traffic lines across the Mississippi and Missouri valleys, with converging points at St. Louis and Kansas City. Trade conditions have made Missouri river points the ones where the last transfer is made when entering the great southwest region, and they are logical points for the building up of manufacturing plants to produce a variety of articles for which transportation costs of finished products are in excess of corresponding costs of transportation of raw materials.

RAW MATERIALS.

The second leading factor is that of the utilization of raw materials. Certain industries are bound to the source of their constituent material, and it may be taken as a fundamental proposition that an enterprise based upon local material is desirable in a twofold sense. Wherever the market may be in such instances, the community derives an advantage not alone from the carrying on of the manufacturing process, but also from activities in connection with the production of the material. Industries in this group include cement manufacturing, and all others in the group of ceramic goods, such as brick, tile and pottery of various sorts; paper from straw or other locally grown fiber; dairy products; and salt and gypsum products.

In another class are the great industries of meat packing and flour milling, raw material for which may be of either local or distant origin. For an industry of this character the producing of the raw material constitutes in itself an important activity. In the beet-sugar and sorghum-syrup enterprises, as in the dairy products, there is applied a direct stimulus to agricultural development in the way of growing of crops or producing of milk, which would have no

market were it not for the final refining or treating plant. Still another activity that deserves much more attention than is now accorded it is the canning and preserving of vegetables and fruit.

The state of Kansas has before it important possibilities in the lines just suggested. A sound industrial system calls for a complete utilization of resources which are natural to the region. This is a fundamental matter. It is true, of course, that such activities are dependent upon market conditions previously discussed, but the fact remains that several of these lines have been neglected in the past. The clay resources of the state are important and widely distributed, and will ultimately become the basis of industries far more extensive than have been developed to date. In the other lines, particularly in manufactured food products, the conditions which make for successful operation will be materially improved under the transportation conditions that are likely to exist in the future. While it is not expected that freight rates on package goods will continue at the present high level, it is equally probable that the rates will remain at some intermediate level such that the transportation cost of all commodities shipped in from distant centers of production will be greater than it was in 1914. Local production to meet the local market will be the result.

CAPITAL.

Three other factors affected by local conditions enter into the problem of development. These are capital, labor, and power. In some degree capital may be considered independent of location. Enterprises which may be established by foreign concerns organized, whether through removal of the producing plant or through the establishment of branches, are financed independently of local conditions. All others are influenced by local banking institutions. It is here that Kansas must look to its business interests for aid in developing for itself an industrial attitude of mind. The banking institutions of the state are founded generally on the agricultural wealth of their communities. They are acquainted with agricultural property and are trained in the handling of agricultural risks. As a rule they are not acquainted with industrial properties, and therefore are hesitant in advancing credit to such organizations. It is a natural condition which exists, but it is one to which serious thought must be given. The first requisite is that proposed industrial developments shall be on a sound basis, free from the criticism that so frequently applies to the schemes put forward by a certain class

of promoters. These enterprises are frequently of such character that they will not stand the test of a genuine analysis of marketing conditions.

The time has come when accurate detailed studies of scientific character are demanded by financial institutions before they embark upon projects, and those wishing to promote these projects must expect to comply with this demand. It is in accord with correct industrial procedure, and men competent to investigate and advise are easily secured. The industrial expert is the outcome of modern conditions and his services are vital to progress.

LABOR.

The conditions as to labor have been commented on in Part I and need not be enlarged upon here. For the industries which have been referred to, and which may be held to be desirable for the region, the labor situation is entirely satisfactory. There is a body of over 60,000 employees in the state, sufficient to furnish nuclei in all of the natural centers of production for many additional enterprises. It is a vigorous and clean group of people, with sound ideas and mainly of good American stock. Exceptions to this statement are to be found in certain points, notably in the coal-mining district and the congested meat-packing center, but the miners are not counted in the 61,000 industrial workers. Conditions of living in all of the representative cities are such as to attract many from other regions, provided employment is obtainable.

POWER.

A separate chapter in this report is devoted entirely to the question of power. In that section will be found the facts pertaining to fuel supply as well as water-power resources. Already a considerable portion of the state is being served with power through electric transmission systems radiating from the larger centers of production. The power companies are progressive and are disposed to extend their lines wherever industrial conditions justify it. In this respect the state is in very favorable condition.

DESIRABLE INDUSTRIES.

As an index of one set of conditions tending to show the desirability of various types of industries, Table V is shown herewith. This includes fifty typical industries of the United States. It is customary to measure the strength of an establishment and its producing capacity in terms of value of product. It is easily shown that this is misleading. Some industries utilize as raw material

commodities which have very little value, while others utilize articles of great value. The difference between the total value of finished product and the value represented by the raw material is a closer indication of the magnitude of the actual manufacturing business. This difference is known as added value. Out of this must be met all of the expenses of operation, such as payment of wages, return on investment, cost of power, and all other general expenses incident to operation. It is a measure of the true wealth-producing power of the establishment.

The industries in Table V are arranged in the order of added value, taken in proportion to total value. A very great difference is noticed, ranging all the way from $93 per $1,000 of total value to $855. From this it is apparent that an industry high in the scale is expending a very much larger amount of money in pay roll and for general expenses in a community than does one which is low in the list but turning out goods of the same gross value.

This is merely a general indication as to the desirability of manufacturing establishments of different types, but it must not be taken too seriously as a real measure of importance. As has been noted in the previous section, industries based upon raw materials which are native to the location are of extreme importance by reason of the encouragement given to the producers of such materials. This is especially true of dairy-products plants and other manufactures based upon agricultural products. Figures from this table are of greatest significance in respect to the light thrown by them upon the relative values. It is not uncommon for large producers to refer to the extent of value of product, and to use that value as a basis on which to compare profits. It is important that everyone should realize that the total amount of investment in a manufacturing institution is related to added value rather than to total value, and that in certain industries standing low in the table a very small percentage of profit based on total value would mean a very large percentage when based on the added value. Such information assists the judgment in deciding upon the relative significance of different types of enterprises in the community. It is not to be concluded that the industry ranking low is undesirable, because, on the contrary, it may be of very great significance in building up the entire producing capacity of the region. It is of more than passing interest, however, to know that many of the industries which Kansas now seems ready to develop in larger volume than before stand high in this list, and are thus seen to be of the kind

TABLE V.

VALUES FROM UNITED STATES CENSUS, 1910.

Industry.	*Value of products, thousands.*	*Added value, thousands.*	*Added value per $1,000 of value.*
Sugar refining, cane	$248,628	$23,190	$93
Slaughtering and meat packing	1,370,568	172,110	126
Flour milling	883,584	128,128	145
Dairy products	274,558	41,430	151
Cottonseed oil and cake	147,868	32,795	222
Blast furnace, iron and steel	391,429	97,041	248
Leather, tanned	327,874	83,155	254
Glucose and starch	48,799	12,532	257
Zinc smelting	34,206	9,453	277
Boots and shoes	512,798	181,512	354
Steel works and rolling mills	985,723	353,722	354
Cordage and twine	61,020	21,650	355
Canning and preserving	157,101	57,202	364
Woolen goods	435,979	159,071	365
Paper bags	15,698	5,796	369
Paint and varnish	124,889	46,901	375
Confectionery	134,796	54,326	403
Paper and wood pulp	267,657	112,965	422
Awnings, tents, etc.	14,499	6,132	423
Dyestuffs and extracts	15,955	6,829	428
Leather goods	104,719	44,985	430
Cotton goods	628,392	277,102	441
Copper, tin and sheet-metal products	199,824	88,222	442
Leather gloves	23,631	10,468	443
Beet sugar	48,122	22,098	459
Hosiery and knit goods	200,144	91,849	459
Chemicals	117,689	55,924	475
Men's clothing	568,077	271,107	477
Automobiles	249,202	119,026	478
Steel springs, car, etc.	9,005	4,412	490
Iron and steel forging	20,293	10,505	518
Electrical machinery	231,308	115,158	520
Boxes, fancy and paper	54,450	29,013	533
Hats, fur, felt	47,865	26,136	546
Locomotives, nonrailroad	31,582	17,278	548
Furniture and refrigerators	239,887	135,422	565
Foundry and machine-shop products	1,228,475	703,004	573
Tobacco manufactures	416,695	240,093	577
Buttons	22,708	13,356	588
Agricultural implements	146,329	87,738	600
Sewing machines	28,262	17,220	610
Emery and abrasive wheels	6,711	4,118	614
Stoves and furnaces	78,853	50,332	638
Cement	63,205	40,982	648
Cutlery and tools	53,266	36,016	676
Pottery and fire-clay products	76,119	56,617	745
Typewriters and supplies	19,719	15,770	800
Brick and tile	92,777	76,376	832
Cash registers and calculating machinery	23,708	20,281	855

that contribute most markedly to the general business welfare of the city in proportion to the total amount of business handled.

Several of these are discussed in detail in the following chapter under "Prospective Developments." Some of them may not stand high in the list with respect to added value, but all are, for some reason or other, of direct importance to the state. Further than this, they are industries that stand a good chance for successful development, which is the element of first importance. Success must be attained in the earlier projects and thus become the basis for additional enterprises. We cannot afford to make mistakes in ways wherein a correct interpretation of conditions would have been possible. No factory is desirable unless it is correctly located for a successful business career.

PART IV.

PROSPECTIVE DEVELOPMENTS.

AS PREVIOUSLY NOTED, industries are to be considered for any community on the bases of market, raw materials, and such attendant factors as labor supply and power. In many of the Kansas towns, however, power and labor conditions may be considered as satisfactorily met, while the elements of capital and transportation are also taken care of. What we have to consider, therefore, is the fact that manufacturing enterprises which may be expected to prosper in the state are of three types, namely:

1. Those which are located with direct reference to the source of raw materials.

2. Those which follow the market by reason of high cost of transportation of the finished product, or because of some other factor making marketing more convenient from a local source.

3. Those which are independent of both the preceding, but which are feasible wherever personal enterprise and ambition may lead men to undertake their promotion.

A limited number of possibilities in each group will be considered with reference to various cities of the state where labor and other conditioning factors are favorable. It is an attempt to answer the ever-recurring question, "What industry can be expected for this town?"

Every one mentioned in the first group is not only a possibility but one that is deserving of consideration. The resources in the several lines should be the bases of much more activity than now exists.

INDUSTRIES BASED ON LOCAL MATERIALS.

Clay Products. Kansas has the possibilities for a great industry in its clays and shales. The products of existing plants include brick, tile, and simple grades of pottery. Vitrified brick are made in Crawford, Montgomery, Wilson, Douglas and Shawnee counties, and this business is limited only by market conditions. Building brick and tile are made in the same counties, and also in Neosho, Anderson, Allen, Linn, Bourbon and Nemaha counties. Clays from Barton, Pawnee, Ellsworth, Ottawa, Cloud, Washington, Cowley

and Franklin counties have been investigated and found suitable for brick, some of these yielding varieties of ornamental goods having special value. The county maps, section II, show the limits of known deposits and the locations of existing plants. From a study of these it appears that additional plants established in several central and eastern counties would be accessible to markets in nearby sections not now served. Railroad connections at these points are ample to care for the product, in each case extending into good market territory both within and without the state. With the more systematic agricultural developments that are on the way, involving irrigation and drainage projects, the demand for agricultural tile is bound to increase.

The only establishment producing pottery in considerable quantity is at Pittsburg, in Crawford county. Only the coarser grades, mainly flower pots, are made. However, the clay there is suited to the production of finer grades of goods having both utilitarian and artistic merit. It is known also that the clays of Montgomery and Barton counties have similar qualities. Undoubtedly there are several other sections where this is true. These deposits constitute an undeveloped opportunity for wealth little realized by most people. It is possible to build up an industry that will produce a line of pottery and specialty ware that would bring distinction for quality as well as financial profit.

Portland Cement. This is another line of ceramic goods that deserves consideration. The eight plants now producing cement are active, and any new project should be preceded by careful study of market demands, but it seems inevitable that conditions will warrant a few more establishments in the next few years. Construction work projected in the state and in adjoining states is calling for increasing quantities. In 1914 Kansas used .81 barrel per capita, about the average for the entire country. Since then the consumption has been increased materially without the addition of any new plants. In the year mentioned it was probably true that the state was oversupplied with producing mills, but that condition has been outgrown.

Materials are found in Leavenworth, Douglas, Cowley, Ellis, Butler and Atchison counties. It is to be remembered that fuel considerations are of great importance in the cement business. Favorable locations are near the cities of Leavenworth, Atchison, El Dorado and Winfield. The first two have their own coal mines and can manufacture at low production cost. The latter two are

better placed to enter the market territory of the Southwest, and also are in direct connection with the coal-producing fields of both Kansas and Oklahoma, as well as being in the center of the best petroleum field of the state.

Dairy Products. This line is so well understood and has so many persons urging development that little need be said here. There are excellent opportunities for condensaries and butter- and cheese-making plants in a dozen or more counties where the farmers have already made beginnings in dairying. It takes time to bring the typical Kansas farmer into the mood to keep cows for real dairy purposes, but in many sections good progress has been made. The organized establishments have made best progress in Bourbon, Shawnee, Sedgwick, Sumner, Atchison, Leavenworth, Dickinson and Anderson counties. Future developments are especially promising in Cowley, Wilson, Montgomery, Reno, Rice, Saline and Marshall counties.

There are two factors of prime importance, basic to a real dairy-products development, which are not fully appreciated by the residents of most of the counties and county-seat towns. They are: first, the improvement of dairy herds by systematic development of the best breeds of cattle; second, the building of a complete system of county highways that will make possible daily deliveries of milk. The last is a matter that calls for particular emphasis because it is so likely to be neglected or underestimated. The set of county maps included in this report shows the progress being made in highway construction. Bourbon, Shawnee, Sedgwick, Reno, Montgomery, Johnson, Wyandotte and Allen counties show favorably in this respect.

Canning and Preserving. Canning of vegetables and fruit is an industry that has been neglected in an unaccountable degree in Kansas. The only well-organized plant is in Lawrence, Douglas county. There are excellent opportunities in a dozen or more sections, either as independent projects or as adjuncts to wholesale houses. They should be established at points like Atchison, Hutchinson, Wichita, Salina, Independence, Parsons, Arkansas City and Pittsburg by reason of the wholesale houses; also at Abilene, Hays, Garden City, Newton, Hiawatha, Holton and Fredonia because of peculiarly favorable conditions for growing vegetables or for securing labor for the short season of employment in the canning plant.

Gypsum Products. The deposits of gypsum warrant further development, but any concern attempting it has need of exercising

considerable care. Both manufacturing and marketing conditions are such that an enterprise should have a good amount of capital behind it and a well-developed marketing system. The maps showing mineral deposits show the locations that may be favorable. It is probably true that a concern in this line should possess basic patents for products that have special qualities in order to insure success.

Paper and Paper Goods. Straw is a basic material for paper, but it should be understood that it is only one of several that are essential to the manufacture of any grade excepting the heavy board suitable for packing, egg-case fillers, etc. The straw fiber is short, giving a soft paper with little tensile strength. For tougher paper essential for most purposes it is necessary to import wood pulp to mix with the straw. Old paper and cotton waste may be worked into the stiff board used in making ordinary boxes, this being called "chip-board." Corrugated board for making heavy packing boxes utilizes strawboard for the inner corrugated layer that gives resistance to crushing loads, but requires a strong, thin paper made of better material for the outer sheets.

Another condition frequently not understood is that paper making requires large amounts of power and heat, calling for fuel in great quantities. This means that locations must be selected favorable to the procuring of coal. Under certain market conditions fuel oil would be an element of significance, but the future of petroleum as a source of fuel for steam boilers holds such doubtful prospects that it seems doubtful if good business judgment would lead to the establishment of a plant at any point where coal may not be depended upon.

Still another matter of first importance is that any plant must carry the manufacturing process to the point of making the product ready for immediate use—not confined to the making of paper alone and selling it to paper-goods plants. The reason for this is mainly one of transportation costs, and it is especially vital if the suggested market for paper is east of the point of production. The basis for adjustment of freight rates is such that a commodity moving from any Kansas town back to a Missouri river point suffers in competition with goods coming from eastern points, unless the plant production cost gives the Kansas article a wide margin. This is not the case with paper, because wood pulp from the northern plants having cheap water power, or even imported from the Scandinavian countries, enjoys the benefit of low cost of production.

With all these questions considered, there is still the possibility of adding to the present paper industry of the state in a limited degree. The market that is local, and growing to the southwest, will absorb more egg-case fillers. There is also a growing demand for paper boxes for such service as for candy, the fancy Christmas-box trade, and miscellaneous uses, as well as for the small ice-cream carton, butter packages, etc. This trade calls for the "chip-board" box, with or without the fancy thin-paper covering bearing specialty designs. The heavy paper packing box is likewise growing in favor, and there is every prospect for a plant given over to its production, in addition to the single one now operating in the state.

There is good reason for selecting Leavenworth and Atchison as the most promising locations for either or both types of plant. Both of these towns have coal at their doors and are in position to draw straw from the rich counties in the northern part of the state. Their railroad connections with the East are satisfactory for bringing in such imported material as might be required. For a plant to turn out egg-case fillers or other articles requiring straw pulp only, Topeka is admirably situated, due to its facilities for distributing to the north and north-central counties.

Leather Tanning. The tanning of leather is an industry subject to many varying influences. While the older processes were in vogue it was cheaper to ship the hides to the sources of hemlock and oak bark used as tanning material. Conditions in this respect have changed, but another strong influence serves to hold the business in the old locations, namely, invested capital, combined with custom and habits of labor. To meet the growing demands for leather, however, it is now feasible to consider, for locations of new enterprises, points in this region. Tanning extracts are readily procured, and the hides do not need to take the journey east to be returned as leather. The logical point for such a plant is Wichita, the center of a considerable hide-producing area. It may be a source of surprise that the great slaughtering center, Kansas City, is not given the preference. Normally this would be done, were it not for certain powerful influences which need not be commented upon here.

INDUSTRIES WHICH FOLLOW THE MARKET.

Important as are the industries based on local materials, it is through those more vitally concerned with markets that Kansas will experience its more immediate development. The great and growing market of the Southwest is the most significant element. Scores

of varieties of enterprises may be organized to meet the demand for staple goods. Attendant upon those to be mentioned here as industries of the first order of advance, are many others that are more or less dependent and which will follow in their wake.

Shoe Manufacturing. Kansas is destined to build up a large business in this line. The industry has been moving westward for years. St. Louis is one of the great shoe towns of the country. Plants tributary to St. Louis have grown up in many east Missouri towns. Independent plants have developed in St. Joseph and Carthage, close to the Kansas line, and already movements are under way to establish branch plants in this state. Two small factories are now operating in Olathe, these being independent concerns turning out specialized goods in the main. A Wichita firm makes a military boot of the finest grade.

Shoe factories call for a class of labor that is plentiful in many cities and towns. It has been demonstrated that the labor available is of a high order and well adapted to the work, through the experience of a factory in Wichita that operated for several years but discontinued because of conditions not at all dependent upon labor supply. The general situation is good. This does not mean that every town is suited to it. Members of typical Kansas families of American stock will not take kindly to factory labor at the start. Gradual development is necessary. Cities now ready for it are Wichita, Kansas City, Topeka, Parsons, Leavenworth, Atchison, Ottawa, Lawrence, Winfield, Fort Scott, El Dorado, Independence, Coffeyville, Arkansas City and Hays. More plants employing men are needed in Hutchinson, Iola and Salina before they are ready to supply the necessary labor. Wichita is the city best adapted to a really notable shoe business, such as may be expected to materialize in the next twenty-five years. It is located favorably to the market and is far enough west of the present centers in St. Joseph and Carthage to become the center of a new group of producing plants. With this there must develop in Wichita the parallel activities employing men in large numbers, however, in order to preserve a normal ratio of men to women in the employed population.

Agricultural Implements. To many this is the line of work that would seem to offer most. The entire region, both in the state and in the Southwest market generally, buys heavily in all kinds of implements and machinery for farm use. True it is that there should be the best of prospects for successful activity in this direc-

tion, but the fact of a market par excellence must not cloud the vision as to other determining influences.

The implement and farm-machinery manufacturing business of the United States is one that has figured largely in the export machinery trade. The producing capacity of the country is now far above the demands of the home market. Hence it is that further development in standard lines will not be possible until the export trade has resumed normal, or more than normal, dimensions, according to conditions set at some intermediate but not definitely specified date during the war. At the present time (June, 1922) this class of equipment is being produced in Germany and laid down in the South American market at prices below production cost in this country. This means simply that time must pass before conditions are such that extensions in staple lines can be looked for in Kansas. A further element is that production costs must be held low, even when the present market lifts so as to make it possible to think of expansion, and this means operating on a large scale under best conditions.

This rather dark picture is not to be taken as a positive forecast, however. There is opportunity for opening up certain specialty lines appropriate to the local market, and for a gradual development of the branch-house business with assembling departments that may take on more and more of manufacturing functions. A start has been made in several towns, so that employment is given to many men. It will be an important industry in the state ultimately. The most favorable locations, considering available labor of proper qualifications, freight charges on raw material from the East, and accessibility to market, are Kansas City, Topeka, Leavenworth, Atchison, Wichita, Hutchinson, Salina, Parsons, Lawrence, Fort Scott and Ottawa. In thus suggesting locations it is recognized that conditions peculiar to some city may have a determining effect quite apart from conclusions here drawn, that are based on general facts. In the machinery-manufacturing business also, in whatever line, the freight-rate situation dictates a location either near enough to the Missouri river so that material from the East may be delivered on the basic river rate, or far enough away from the river toward the market so that there is a compensating difference on cost of transportation of the finished product. Of the above towns, Parsons and Fort Scott enjoy connection from St. Louis without passing through the Kansas City yards, but, on the other hand, their market connections do not represent so general a demand, although extend-

ing directly into the cotton belt of Oklahoma and Texas. A somewhat similar statement may be made concerning Leavenworth and Atchison, relative to Chicago connections, and with market possibilities ranging northwestward rather than south.

Furniture. This is a promising line for a considerable number of towns. Leavenworth already has a substantial business. Independence and Wichita also have establishments which have developed specialty goods as outgrowths of general planing-mill work, while Topeka, Garnett, and Fort Scott have mills which are doing more than a local business. Topeka also has a rapidly developing plant producing sheet-metal cabinet work. Lawrence has an organ-building plant employing a good number of highly skilled men. It is but a step from such beginnings to more fully developed producing establishments which call for the highest types of labor. Any one of a dozen or more of the leading cities is in prime condition to foster a substantial enterprise. In several towns it so happens that there are planing mills which have good business connections, but at present undercapitalized. Parties looking for openings will find excellent opportunities to step into such plants and build up various lines of goods. Specific information as to these openings will be given on request.

Metal Manufactures. There is a varied line of metal products that should be made in the state. Several have been developed already and there are a few interesting plants that deserve special mention. The Locomotive Finished Material Company, in Atchison, does an extensive business with the railroads. The Great Western Manufacturing Company and the Fisher Machine Works, in Leavenworth, produce a variety of products, including engines and ice machinery. The Griffin Wheel Company, in Kansas City, is a large producer of car wheels. The Ottawa Manufacturing Company builds gas and oil engines. Three plants of the United Iron Works Company, in Iola, Pittsburg and Independence, do an extensive business in oil-field and coal-mining equipment. Ersham Brothers, in Enterprise, have a large business in gypsum-mill equipment and flour-mill repair work. The Coleman Lamp Company, in Wichita, has an extended business in gasoline lamps and lighting systems, specialty goods. The Perfection Metal Products Company, in Topeka, is a leading producer of metal tanks and elevators. Railroad cars are built by four large concerns other than the railroad shops themselves—one at Ottawa for general service and three at Coffeyville for oil-tank cars. These with many smaller plants and

the railroad shops employ 18,000 metal workers—the working basis for a future metal-products business of large scope.

Types of products that should be developed to a much greater extent are: gas engines for farm use, wind mills, pumps for irrigation and general service, steel oil barrels, and tractors. Many other articles of miscellaneous nature and specialty goods of various kinds may be added to the list. Anyone desiring to start production of a patented article for the general market will find favorable opportunity.

A most important adjunct to the iron and steel goods industry in the Missouri river valley, and one that should be developed at or near Kansas City, is the manufacture of steel itself. This business is being carried on on a moderate scale in the Kansas City (Mo.) district, and is capable of great enlargement. The scrap iron and steel from the agricultural and oil-producing regions is of the highest grade for reworking in open-hearth furnaces, and it should be unnecessary for this material to be transported to eastern points and the finished product reshipped for use in this region. This is worthy of most serious consideration. It is possible to build up an important and profitable industry, favored, as it would be, by a marginal figure of $10 to $16 per ton of steel represented by the double transportation costs of so large a part of the metal used in contiguous territory.

Cities of the state that are well conditioned for the metal-goods business with respect to labor, power and transportation, and which have not been mentioned in this section, are Hutchinson, Salina, Parsons, Arkansas City, Lawrence, Newton, Fort Scott, Chanute, Fredonia, Herington, Concordia, Manhattan, Marysville, El Dorado, Winfield and Wellington. Cities farther west, placed so as to draw from Colorado supplies of fuel, iron and steel, and which have already developed activities in these lines, are Belleville, Garden City, Dodge City, Norton, Ellis, Hays, Scott City, Great Bend, Larned and Ellsworth.

Leather Goods. Atchison is the leading city in the leather-goods business, with Wichita and Topeka following. Hutchinson, Salina, Pittsburg and Independence are other towns where there is special opportunity for successful development because of labor and marketing conditions. This is a type of manufacturing that might be promoted with good effect in any one of a score of other towns, however. It calls mainly for individual interest and ambition on the part of some one possessed of a moderate amount of capital.

Work Clothing. Into this group fall all kinds of articles such as overalls, jumpers, coarse shirts, work aprons of various materials, caps and work gloves. It is an industry calling for careful study of the supply of women workers and of marketing agencies. Frequently a manufacturing enterprise has developed from the need of a wholesale or jobbing house for a constant supply of the goods in question. Others are independent concerns selling to numerous jobbing houses, in which category fall the largest producers. Several of the plants now in the state are branches of such large concerns, placed at points where workers are available.

There are plants in Atchison, Arkansas City, Fort Scott, Hutchinson, Iola, Lawrence, Kansas City, Newton and Wichita, producing general goods, and the Hamilton Glove Company in Leavenworth. From consideration of relatively few employment opportunities for women as compared with number of men employed in the same towns, it would appear that Atchison, Arkansas City, Fort Scott and Newton could support more enterprises of this kind, while El Dorado, Emporia, Independence, Neodesha, Ottawa, Manhattan, Pittsburg, Winfield and Hays are favorable locations. It is to be remembered, however, that other elements must be considered.

An illustration of what is meant by the last statement is afforded by Salina. Figures on employed persons would indicate that more women would be found seeking employment. Salina is a wealthy city, however, and a very large portion of its population is inclined to shun factory labor. Another factor is the prominent wholesale firm located there, which has its own garment factory in Kansas City. When conditions are ripe for a garment factory in Salina, that firm is the one to establish it.

Wichita should become the center of a large business in this line. Its wholesale houses cover a territory in which are many thousands of oil-field workers and railroad shop and operating employees, as well as an exceedingly rich and populous farming territory. An extensive establishment in that city, either as an adjunct to some wholesale house or as an independent firm, would find a good field. The near-by cities of El Dorado, Winfield, Arkansas City, Wellington, Newton, Pratt, Anthony and Mulvane furnish especially favorable locations for branches that would function from such a central plant. Unquestionably this constitutes the best plan of development and the best prospect for a large business in this line to be found anywhere in the state.

The next best point for building such a business is at Parsons.

Over the Missouri, Kansas and Texas lines a large consuming territory is reached, and there is a good wholesale business already developed. Near-by cities of Pittsburg, Fort Scott, Chanute, Erie, Cherryvale, Independence, Coffeyville and Columbus furnish the locations for branches centering at this point.

Any established firm wishing to locate a branch in the western section would do well to consider Hays. Labor conditions there are especially good.

A General Group of industrial activities which tend to follow the market, but the members of which will not be discussed in detail, includes the following, some of which are worthy of careful consideration:

Builders' hardware, including art metal work.
Roofing tile, and imitation metal tile, zinc shingles, etc.
Wooden baskets for fruit and miscellaneous use; assembling plants using material shipped in in flats (one plant now in Kansas City).
Specialized types of furnaces and burners for oil fuel.
Steel office furniture and fixtures (one plant now in Topeka).
Automobile accessories.
Brushes and brooms (several of the latter now operating).
Paper and canvas bags.

INDUSTRIES LOCATED INDEPENDENTLY OF MATERIALS AND MARKETS.

Activities coming within this group are so numerous that it is impossible to select any distinctive list that will not be faulty through omissions. It is not meant that materials and markets are not of direct importance, but rather that these enterprises depend upon initiative and energy in the persons who have the desire or special aptitude for their development. The possibilities of marketing must be studied, of course. Products must be sold. But as a rule these products bear about the same transportation charges as do the raw materials, so that it makes little difference where the plants are located in that respect. Economy in production is essential, which means that labor, power and local financial conditions must be favorable. There are many interesting examples to be found in every part of the country of successful enterprises that are so simply because of the mastering influence of men who have been interested in building along those special lines. This influence will sometimes overcome real handicaps, and for industries in this class it is the element that brings success. Some of the products listed in the general group in the preceding section might be included here, sharply drawn lines of distinction being impossible.

Textiles. A characteristic of the textile industries has always been that the notable centers of manufacturing have been at points distant from the sources of both cotton and wool. Witness the important activities in England, western Europe, and the North Atlantic States. Only in recent years has there been any marked tendency to develop cotton mills in the Southern states. These have proven successful, especially in producing the coarser fabrics.

Aside from custom and habit there are three factors influencing the production of both cotton and woolen goods—namely, labor, power, and climate. Power is of more significance in cotton mills, and climate in woolen. A humid atmosphere is necessary to keep the fibers soft and pliable and so permit drawing into the finer grades of yarn or thread. In this region it would be necessary to wash and humidify the air—a thing which is being done in many localities in the East now. It constitutes a moderate handicap. The question then arises as to whether this handicap can be offset by a saving in transporting wool—for instance, to the eastern mills and the yarn back to Kansas. It depends on how much yarn is used in Kansas and the adjoining states.

In the case of woolen goods there is a possibility for development in the state. It is based on the development of an associated industry—the knit-goods business—to build a market for yarn. It is a matter that has been discussed frequently, and for success there must be a general program adopted covering both spinning of yarn and utilization of the yarn in garment-making plants. The wool in the Kansas market is of inferior grade, and only the coarser varieties of knit garments could be produced. Better grades from the growers of Wyoming and the Northwest might be forthcoming in time. When some group of men with plenty of capital at their command is ready to take up the project it can be worked out with good chance for success. A somewhat similar statement may be made for cotton. Further than this nothing will be said regarding textiles.

Paper Boxes. This comes near being an industry tending to follow the market, because of the great bulk in proportion to weight of the product, thus making transportation expensive. The distinctive centers of manufacture, however, are Milwaukee, St. Louis, and, to lesser extent, Kansas City, Mo., with respect to the general western market. There is a small business in the state and one moderate-sized plant in Oklahoma City. The market is especially good for boxes for the growing candy-making industry in the region, for ice-cream cartons, butter-packing boxes, and for the fancy

Christmas holly boxes. This has been referred to under the heading of paper and paper goods.

It is an industry employing women in large proportion. An ideal location for a plant is Ottawa. From that point the Santa Fe railroad has direct lines to all the candy factories of prominence, at Iola, Pittsburg, Wichita, Hutchinson and Salina; it has two lines into Oklahoma and two into Colorado and New Mexico. The same lines serve directly the greatest creamery areas of the state.

Pressed-metal Goods. There is abundant opportunity for a successful development in this line. The articles which could be produced are numberless in variety, including buckets, cups, dishes, trays, novelty goods, fasteners, ferrules, hooks, cornices, and scores of others. Enameling and other treating processes extend the scope in interesting ways. It is adaptable to piece-work labor for part-time workers and would find conditions favorable in cities having large student populations, as Lawrence, Manhattan, Emporia, and Pittsburg where many young people of the best types are seeking employment. Lawrence now has a small establishment capable of becoming the nucleus of a large industry.

Machine-shop Products. In addition to products mentioned in the preceding section under metal manufactures, there are various kinds of articles that might well be produced in the state wherever labor conditions are satisfactory. The list includes metal and wood-turning lathes, drill presses, shapers, and a variety of garage tool equipment; small tools auxiliary to machine tools and for farm use and other services; hardware of various sorts, and specialty goods. Such establishments are among the most desirable that could be found from the standpoint of attracting the best types of employees and giving work to young men growing up in the several communities.

Many other industries might be mentioned, but the list will not be prolonged.

PART V.

POWER RESOURCES OF KANSAS.

AN ELEMENT in the present and prospective industrial activities of Kansas that calls for careful scrutiny is that of power. This is something which calls for no extended discussion as to its necessity, since it is appreciated by all that adequate and reliable supplies must be at hand for all purposes. It is desirable, however, that there be full understanding as to present generating capacities of plants at the strategic points and the supplies of the fuel resources that may be depended upon in the future. Distribution is an important factor in this.

WATER POWER.

Since the economical production of power is naturally associated with water-power development, in service and prospective, this phase will be treated first. The number of hydraulic plants is greater than may be supposed to exist in the state. At this time there are twenty-three plants, aggregating 9,572 horsepower, in operation. It is estimated by the United States Geological Survey that in 1920 there were utilized by the public utilities 20,697,000 kw. hours. In addition to this, nine out of the twenty-three plants are employed exclusively by private milling companies. The accompanying map shows the locations of these developments and of several undeveloped sites.

Many of the plants that are operated in conjunction with steam plants are employed as auxiliaries, in distinction to the older practice of making the steam units auxiliary to the water units. The significance of this is evident after a little reflection. The dominating characteristics of the rivers of this section are the low gradients of the stream beds and the pronounced variations in flow. High-water flow is very large, comparatively, and for long periods low water conditions prevail. Storage is limited usually to that obtainable in the pondage immediately above the dam, and while the low gradient of the bed makes this considerable as compared with that form of storage in other sections of the country, it is not sufficient to carry the plant appreciably above low-water-flow capacity if it is drawn upon continuously. If the plant is operated during only a

few hours each day, however, the natural flow of the stream can be stored in the pond during the others hours of the day, and so made available for short-time service. By this means the water plant can be depended upon to deliver power at rates two or three times that represented by low-water flow, and so help very materially to meet the peak-load demand for several hours at a stretch.

This method of utilizing water power makes it possible to design the steam plant with economical generating equipment that may be operated with small variation in load at high efficiency for full 24-hour periods, drawing upon the water for the excess power during the peaks of the demand. This makes for economy in both plants, avoiding the stand-by losses incident to holding steam boilers in readiness for intermittent service. Recent achievements in perfecting electric automatic control systems, by means of which the water-power equipment may be started as needed without calling for action of men stationed at the water plant, reduces the demand for attendant labor. One crew of skilled operators at the steam plant may care for both. One of the largest service companies in the state is employing this method to great advantage, having several generating stations of both kinds in its system, and so being able to balance its load effectively. This company serves fifty or more cities and towns, and has already extended its transmission lines through twelve counties.

There are additional developments of water power possible within the state, aggregating probably 4,000 horsepower. This does not include a most important development that is considered feasible on the Missouri river at a point adjoining one of the northern counties. The present industrial demand does not warrant this being made at the present time, but it is a latent source of power for the future. When made it will rival the great project on the Mississippi at Keokuk.

NOTABLE POWER SYSTEMS.

There are several power companies in the state that are equipped for service of more than local character. The extent of the service lines is shown on the accompanying map. Extensive as these now are, they do not show the full capacity of the companies, some of which have not yet built these lines, or at least have not carried them to the limits to which they will go ultimately as demands increase.

The largest system in respect to the extent of territory served is that of the United Light and Power Company, with head offices in

Abilene. It has 600 miles of transmission line and serves about sixty cities and towns. It generates power in eight steam plants and four water-power plants. It has recently extended its service westward and is ready to connect with Wichita and Hutchinson systems in the central part of the state. It is equipped to give complete service in all of the towns which it touches.

The Kansas Gas and Electric Company has its generating plant at Wichita. Its policy differs from that of the last-mentioned company in that it operates a small number of generating plants. It is purchasing power for its eastern lines from the Empire District Company. It has on foot plans for enlargement of capacity on a large scale. A notable feature of its business is the sale of power to the extensive oil-producing interests in the central Kansas field, especially in Butler county, where applications of electricity to this line of work have been developed to an unusual degree. This company serves Sedgwick, Butler, Cowley and Harvey counties and adjacent territory from its Wichita and Arkansas City plants, and the cities of Pittsburg, Independence, Cherryvale, with other towns in Crawford, Montgomery and Labette counties from either the Pittsburg or Independence plant or with power purchased from the Empire company.

The Empire District Power Company operates mainly in the lead and zinc mining district and the city of Joplin, Mo. It has one plant in Kansas, in Cherokee county, a strictly modern plant of over 20,000 kilowatt capacity. In times of mining activity in the lead and zinc field the larger part of the power is used outside the state, although the mines and towns of Cherokee county use considerable current. The company lines are connected with the Kansas Gas and Electric Company line near Pittsburg, for delivery of current sold to the latter company.

The Union Light and Power Company, of Hutchinson, operates its one plant in that city. It has about 135 miles of transmission line to towns west and southwest. It is connected with both the United Light and Power Company and the Kansas Gas and Electric Company.

There are smaller systems radiating from several cities in central and western Kansas, the most prominent being those at Concordia, Dodge City and Garden City. These are so situated with respect to the larger systems separately mentioned that connections may be made readily and the entire group made to operate as one interlocking system. It is a fortunate situation, promising an ultimate development comparable, on a relatively moderate scale, with the

super-power project of the Atlantic seaboard. It operates over the entire industrial section of the state, excepting an area in the eastern end which falls within a radius of about 125 miles of Kansas City. Concerning this important area the following paragraphs give the present situation.

The Kansas City (Mo.) Power and Light Company has recently added to its developing capacity a new station of 60,000 kilowatts. It is a model station that ranks among the best in the country. It is the announced policy to extend lines to such areas within a radius of 100 miles as may provide suitable loads. A line has already been built a few miles into Kansas. Through this agency the eastern portion of the state just referred to will be served to considerable extent.

Another company has acquired plants at Leavenworth, Atchison, Lawrence and several smaller cities, and is now engaged in projecting a transmission system that will cover an important portion of this eastern section. It is an important project and will figure heavily in the industrial growth of the region.

In addition to the companies which are developing the general service features through long-distance transmission, there are several individual city plants of considerable size. The best known is that of Kansas City, Kan., a notable plant among those municipally owned. The situation in Topeka is not so well in hand at this time, there being but small reserve capacity in the privately owned plant. A small municipal station is in shape to serve industrial users in a moderate way. The situation will be remedied soon. Norton, in the northwestern part of the state, has a good plant, serving several towns besides itself. Ottawa is developing a first-class municipally owned station that will be in position to transmit power to neighboring communities. Many other cities of intermediate size are sending out short lines in addition to serving themselves.

In general, the situation is well in hand. In only a few towns of industrial significance would there be any difficulty in meeting the needs of any firm seeking power service. It may be stated further that progress in extending power service is being made at a faster rate than even the most sanguine are looking for in the growth of industrial demand, so that no apprehension as to service need be felt. Power rates are shown in Table III with the general industrial data, for both domestic lighting and for industrial purposes. The latter is taken on the basis of a moderate-sized plant utilizing 25,000 kw. hours per month.

FUEL SUPPLIES.

A question of more vital import in power matters pertains to the fuel supply and cost. Many industries of the larger establishment type habitually generate their own power, usually in conjunction with the providing of heat for process purposes. It is inevitable that on the fuel situation hinges in great measure the possibilities for material developments in important industries.

The distribution of the producing fields for coal, oil and gas is indicated on the accompanying map of the state. The coal supply is of especial significance, representing, as it does, the more lasting and permanent source of fuel for industrial purposes. The leading section is in the southeastern counties, mainly in Crawford and Cherokee. From this field about ninety per cent of the total product of the state has been drawn. The workable vein lies relatively near the surface there, the portion in Cherokee and southern Crawford counties being operated by the strip-pit method. This field has a supply that will last, under present rate of production, for twenty-five or thirty years.

North of this field, mainly in Linn county, a promising vein in a different geological stratum has been opened up. While it has not been investigated completely, it is predicted on good authority that this will prove to become a most important source, capable of maintaining the normal output of the state for an indefinite period.

The field second in importance among present producing areas is that in Leavenworth and Atchison counties. This is a deep vein, over 700 feet below the surface. Several mines are in operation successfully, and the field is capable of much more extensive development.

The Osage county field is of lesser importance as regards both quantity and general quality of the coal. Several small mines are in operation, but the output is of only local significance.

The coal fields of Oklahoma, Colorado and New Mexico are of significance to Kansas. Certain of the southern cities draw naturally from Oklahoma, which coal is of a high grade for steaming purposes. Similarly, the western part of the state draws from Colorado. The New Mexico coal is of significance mainly because it cokes to advantage, yielding a fair quality of metallurgical coke. There are possibilities for this field being developed so as to become an important asset for the iron-working industries, especially for towns some distance west of the Missouri river, where freight rates from the eastern coke markets rise to high levels. With all these

Figure 4.

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sources to draw from, there can be no concern as to the continued availability of coal. The freight rates are shown for the principal cities, in the general table and also on the map (figure 2) giving general transportation information.

Great interest attaches to the oil and gas developments of the state because of a double significance. This class of fuel is of direct importance in relation to power production under present oil prices. It cannot be estimated how long prices may remain at a level making it economical to use oil for steam-generating purposes. In 1919 the industries of the state used 3,168,330 barrels of fuel oil. This does not include nearly a million barrels consumed by the public utilities. Since 1919 the use of oil has increased materially. Oil is also of direct importance when refined and marketed for general consumption. It represents an industry of great magnitude, and new fields being brought in at intervals over extended sections give promise of continued activity for many years. Under present conditions natural gas figures but slightly in an industrial way, excepting in a few localities. The state map and the several county maps show the extent and distribution of both oil and gas.

PART VI.

INDUSTRIAL MAP SECTION.

IN THE separate map section are shown industrial maps of twenty-three cities and of twenty-eight counties, each group arranged in alphabetical order. The cities shown are Abilene, Atchison, Chanute, Cherryvale, Coffeyville, Concordia, Emporia, Fort Scott, Great Bend, Hutchinson, Independence, Iola, Kansas City, Lawrence, Leavenworth, Manhattan, Ottawa, Parsons, Pittsburg, Salina, Topeka, Wichita and Winfield. The counties are Allen, Atchison, Barton, Bourbon, Butler, Cherokee, Cloud, Cowley, Crawford, Dickinson, Douglas, Franklin, Harvey, Labette, Leavenworth, Marshall, Montgomery, Neosho, Reno, Rice, Riley and Geary, Saline, Sedgwick, Shawnee, Sumner, Wilson and Wyandotte.

Special importance attaches to an industrial map of any thriving community. As made up in this report, the location of every organized industry has been indicated, and the name of the plant given on an accompanying tabular list. Main traffic lines are shown, both railroad and street. In many instances the locations of available sites for new industries are shown. In all of them it is easy to note the sections adjacent to railroads and waterways, which are bound to make favorable locations.

Many of the city maps are suggestive of town-development systems. As the industrial activity of our various communities increases, the people must begin to give more and more attention to the grouping of industries in accordance with a systematic plan, for the good of the town in its community life, and for the industry as well. A study of the twenty-three cities included in the list will show a number of different systems which have been adopted, unconsciously perhaps, but which still portray consistent progress toward the end of making for our towns well-balanced plans which will be favorable to the best interests of all.

It may be remarked in passing that Kansas City is especially favorable in several respects. It has all the advantages which should make it a great and growing center of industry. Its water and traffic ways are so placed as to be available to large areas of unoccupied land available for future industries. To the west and

northwest it has a wide expanse of high and rolling country, admirably suited to residences. The same is true in the region to the south.

Wichita, Topeka, Hutchinson, Leavenworth, Atchison, Parsons and several others have a distribution of industries in a markedly different relationship to the better residence areas. The plants have followed the railroad lines, with slight reference to waterways or topography. In some cases the result has been to split the town into sections, with variations according to the peculiar conditions in each locality. In some of these cities it will be necessary to go outside present limits to find sites adjacent to railroads, if material development is to take place. This tendency is likely to result in a wide separation of residence and business sectors. It is important that these towns should take up the problem, as Hutchinson already has done, so that areas desirable for public park purposes should be thus designated and the city sectors for the several purposes laid out.

Town agencies interested in the securing of industries may well follow the example set by Kansas City with respect to the gathering of information and acquirement of optional rights on land best adapted, in accordance with the city plans, for industrial purposes. This is a wise policy and one appropriately entered upon, even though the prospect for new industries may appear to be remote. Enterprise and activity in all these lines will be well rewarded.

The county maps serve a somewhat different purpose. They are prepared to show especially the transportation facilities, both railroads and improved highways; power and transmission lines; natural resources, especially fuels and workable clays, shales and limestones; and existing plant developments outside the cities that are mapped.

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